Illuminating Engineering

TRANSACTIONS

OF THE

ILLUMINATING ENGINEERING SOCIETY

VOL. V

JANUARY - DECEMBER

1910

Subject Index and Index to Authors

OFFICE OF THE GENERAL SECRETARY
29 WEST THIRTY-NINTH STREET
NEW YORK

SUBJECT INDEX

INDEX TO AUTHORS

The letter C indicates contribution; the letter D indicates discussion.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. V. JANUARY, 1910. NO. 1

MINUTES OF COUNCIL MEETING.

MEETING OF DECEMBER 9, 1910.

Present:—Mr. W. H. Gartley, President, Dr. C. H. Sharp, Dr A. C. McAllister, Mr. C. O. Bond, Mr. Preston S. Millar, General Secretary.

The General Secretary reported as follows:

In accordance with directions of the Council, a congratulatory cablegram had been sent to the Illuminating Engineering Society upon the occasion of its inaugural meeting. An acknowledgment of the receipt of the cable, as well as of the congratulatory resolution adopted at our recent convention have been received.

Obeying the directions of the Council, the American Gas Institute has been notified of the interest which the Illuminating Engineering Society takes in the Zurich Congress, and has been requested to consider the Illuminating Engineering Society's desire for representation on the American delegation to that Congress. The receipt of this communication has been acknowledged with word that it would be placed before the proper body of the Gas Institute.

The monthly statement showing the financial status of the Society was submitted and considered by the Council.

Ninety-nine (99) persons were dropped from membership on December 1st in accordance with a resolution adopted at the last Council meeting. These persons were delinquent in the payment of dues.

Bills payable, amounting to $395.51, and approved by the Chairman of the Finance Committee, were ordered paid.

The following applications, duly endorsed and duly approved by either the general Board of Examiners or Section Member-

ship Committees, were submitted, and the applicants were elected to membership:

BLOOD, CHARLES E., Salesman, General Gas Light Co., N. Y., Young's Hotel, Boston, Mass.

ELLINGER, EDGAR, Engineer, 50 Church St., New York.

GILLINDER, EDWIN B., Glass Manufacturer, 217 West Penn Street, Germantown, Philadelphia, Pa.

HUNTTING, J. R., Gas Appliance Salesman, 184 Summer Street, Boston, Mass.

KELLEY, JOHN P., 1446 S. 52nd Street, Philadelphia, Pa. (Photometrist).

KEMBLE, PARKER H., Advertising Itg. Expert, 360 Pearl Street, Brooklyn, New York.

MASON, EDWARD JARVIS KING, Prof. Elec. Engineering, University of Pittsburg, Grant Boulevard, Pittsburg, Pa.

RICHARDSON, HENRY F., care of Henry C. Meyer, Jr., 1 Madison Avenue, New York, N. Y.

STRAUSS, LAWRENCE L., Electrical Contractor, 13 East 125th Street, New York, N. Y.

TRIMBLE, MILTON E., Special Tungsten Lamp Representative, General Electric Co., 30 Church St., New York, N. Y.

The resignations of Messrs. H. Reinach, James D. Perkins and Herman vonHolst, to take effect December 31st, 1909, were received and accepted.

With a view to stimulating and maintaining the interest of such members as reside at too remote distances from the headquarters of the various sections to enable them to keep in touch with the activities of those sections, and in order that each member of the Society may be identified with some section, the General Secretary was requested to communicate with the various section secretaries with reference to the desirability of placing such names upon their rolls with regard to geographical location.

The Report of the Chairman of the Finance Committee was read and accepted.

REPORT OF THE FINANCE COMMITTEE.

To the Council of the Illuminating Engineering Society.

GENTLEMEN:—In their report of November 11th your Committee gave an estimate of the expense of the Society for the year 1909, based on the vouchers approved to October 12th. This figure was $5,513.00.

Your Committee have since made another estimate, based on vouchers approved by it to date and have obtained approximately the same result, viz: $5,544., which sum is $219. higher than the estimate of April 8th, the first estimate submitted. As in the last report, so also in this, the above estimate does not include the sum of $500. appropriated from surplus by the Council on September 9th last, nor any expenses for the Municipal Art Exhibit for which a special appropriation was also made.

Your Committee called attention in the last report to the fact that the estimated expenses were almost covered by the membership dues for 1909 collected up to November 1st, which collections amounted to $5,465. This sum is only $79.00 under the latest expense estimate, and it is possible that this difference has already been made up by collections since November 1st, since at the time of the last Council meeting the unpaid dues amounted to $785.00 (150 members in arrears for year's dues, 14 members for half year's dues—see minutes of Council meeting of November 11th).

Respectfully submitted,

(Signed) J. S. CODMAN,
Chairman.

ESTIMATE OF EXPENSES FOR 1909.

Rent (Jan. to June at $17, July to Dec. at $33 per month)	$ 300.00
General Office Expenses, actual to Dec. 3rd, $588.01	650.00
New York Section, pro rata on 8 meetings	338.00
Transactions, Mr. Elliott's estimate of May 13th	2,500.00
(Actual to Dec. 3rd, $1,509.60.)	
Philadelphia Section, pro rata on 7 meetings	187.00
New England Section, pro rata on 7 meetings	166.00
Chicago Section, pro rata on 8 meetings	154.00
Badges, Certificates and pins, actual to Dec. 3rd	68.10
Office salaries, vouchers to Oct. 1st, $274.72; Oct.-Dec., $324.96	599.68
Postage, to Dec. 3rd, not included in General Office Expenses	40.50
Advertising, actual to Dec. 3rd	4.76
Property	353.89
Roll of Membership	151.80
Convention, reporting Steinmetz	30.53
	$5,544.26

Communications were read from the following:

Mr. A. J. Marshall, Secretary of the New York Section,

to the effect that a division of membership at this time, in the judgment of the New York Section, is premature, this being in accordance with a resolution of said section on the occasion of its meeting of November 11, 1909.

Mr. Edward Wray, Associate Editor of the "*Railway Electrical Engineer,*" requesting an exchange of publication.

The request was acceded to.

The Librarian of the University of Michigan, asking if it be possible to furnish the Library with complimentary copies of Volumes I, II, III and IV of TRANSACTIONS.

The Council directed the General Secretary to communicate with the Librarian in question in an endeavor to secure Society membership from the University as a possible condition precedent to complying with the request.

The President appointed Messrs. V. R. Lansingh, C. A. Littlefield and E. L. Elliott a Committee of Arrangements for the Annual Meeting.

Messrs. E. F. Tweedy, A. J. Marshall and H. Thurston Owens were appointed to act as tellers for the annual election, President announcing that he would make known the names of two additional tellers at a later date.

In accordance with the above Messrs. F. H. Kinnicutt and Frank B. Rae were appointed as tellers.

The Chairman of the Publication Committee reported that there are very few copies of the TRANSACTIONS of the earlier years of publication, and recommended that the supply be augmented by having the diminished numbers reprinted.

This matter was referred until the next meeting of the Council, when an accurate statement of the cost of replenishing the volumes is to be submitted.

It was decided to extend invitations to the following named gentlemen to become the guests of the Society upon the occasion of the next Annual Meeting:

Messrs. William R. Addicks, John W. Lieb, Jr., Walton Clark, Dr. A. C. Humphreys and Dr. C. P. Steinmetz.

SECRETARY'S ANNUAL REPORT TO THE COUNCIL, 1909.

To the Council:—

The Constitution, in imposing upon the General Secretary the task of preparing an annual report, gives no indication as to the character of scope which is desirable for such report. Nor does precedent lend any guidance. In consequence it has been necessary to choose independently in these matters, and it has seemed best to endeavor to review the year in the hope of discerning the significance of events and their effect upon the trend of the Society's development. If I shall seem to wander from the direct course of events or to poach upon the preserves of other officers or committees, please remember that there is hardly a phase of the Society's activities with which the Secretary's duties do not bring him into touch.

MEMBERSHIP.

Analysis of Membership Changes.—The following tabulation shows a brief analysis of the changes in membership which have taken place during the year.

CHANGE IN MEMBERSHIP DURING 1909.

	Chicago Section	New England Section	New York Section	Phila. Section	Not Affiliated with Section	Total
Members in good standing at beginning of year	108	113	350	229	205	1,005
New members elected during year	53	18	49	58	28	206
Reinstated	1	0	3	1	1	6
Resignations	7	9	21	19	21	71
Dropped for non-payment of dues	29	7	23	10	29	98
Deaths	0	0	1	2	1	4
Membership at end of year	126	115	357	257	183	1,038

NOTE.—The classification among the sections is more or less arbitrary.

Members Dropped.—Numerically, the Society has a little more than held its own. And this, notwithstanding the dropping from our rolls of 98 members who have failed to pay dues for the current year. To drop nearly one-tenth of the entire membership

for non-payment of dues required considerable courage on the part of the Council of a society so young as our own. In itself this action is indicative of a feeling of strength by those who best know the Society's condition. Of those dropped, many were men living in remote places and therefore not able to attend either general or section meetings. When one considers the record in the membership which is directly affiliated with sections, the figures are much more favorable.

Increase in Members Connected with Gas Industry.—The feature of membership change, and one which does not appear from the table, is the increase in the number of members connected with the gas industry. Due largely to the efforts of our President, and more or less as a direct consequence of his encumbency, the proportion of new members added to our roll during the year who are connected with the gas industry, is over 50 per cent. This ratio is about double that which prevailed at the beginning of the year.

No New Membership Campaign.—There has been no new membership campaign, and we have had this year no new membership committee. Such accessions as there have been, resulted from the applicants' initiative or from sporadic efforts of individual members. The appointment of a New Membership Committee for the coming year should receive the consideration of the new administration.

Deaths.—Five deaths have occurred among our membership, as follows:

Mr. J. C. Fish, Charter Member, President National Electric Lamp Association, and President Shelby Electric Company, Shelby, Ohio.

Mr. Samuel A. Fisher, associated with the Philadelphia Electric Company.

Mr. T. J. Hayward, associated with Bartlett, Hayward & Company, New York.

Mr. J. T. Marshall, Charter Member, Assistant Engineer Lamp Works, General Electric Company, Harrison, N. J.

Mr. John Ozanian, General Manager, Pennsylvania Gas Fixture Company, Philadelphia, Pa.

SECTIONS.

Section Activities.—No new sections have been formed during the year, although consideration has been given to the formation of a section in Cleveland, Ohio. This is a matter which will have to be disposed of at a later date. A brief survey of sectional activities during the year appears in the following tabulation:—

	Chicago	New England	New York	Phila.	Total
Present officers elected in	June, '09	Jan., '09	Jan., '09	June, '09	
Terms of office expire	June, '10	June, '10	June, '10	June, '10	
Approximate number technical meetings held	7	9	9	8	33
Average attendance at meetings	50	30	40	85	
Number papers contributed to Transactions	3	6	8	8	25

Sections Supported by Lighting Companies.—In each of the four sections the support of the local gas and electric companies is enjoyed. In all sections, that part of the section management assumed by persons connected with the local lighting industries is rather evenly divided between the gas and the electric interests. In the New York Section, the illuminating engineering interests predominate in the management of the section.

COMMITTEES.

Sub-Committee on Unit of Light.—One of the Society's important functions lies in promoting the cause of standardization in its own field. The Committee on Standards and Nomenclature, through its Sub-Committee on Unit of Light, has already won its spurs, the past year having witnessed the consummation of the Society's efforts toward international standardization of the unit of light intensity. This movement, inaugurated by this Society, and carried through in co-operation with the American Institute of Electrical Engineers and the American Gas Institute, working through the Bureau of Standards, has been creditable to all parties concerned and has been of great assistance in aiding the Illuminating Engineering Society to establish itself technically.

Sub-Committee on Photometric Units.—Another sub-committee—that on Photometric Units—has taken hold in a manner which bids fair to bring results. Witness, its tenative report presented to the last Convention.

Proposed Research Committee. Proposed Sub-Committee on Heterochromatic Photometry.—This year the time seemed ripe for the appointment of a Research Committee, which, like the Committee on Standards and Nomenclature, should work largely through sub-committees upon such questions as may come before it from time to time. Members assembled at the Annual Convention requested the President to appoint a Committee on Heterochromatic Photometry, which committee would naturally be a Sub-Committee of the Research Committee. The Council, to fulfill Constitutional requirements, has balloted in favor of the appointment of a Research Committee and a Committee on Heterochromatic Photometry, but the important question of personnel has required so much thought that the appointments have been left to the incoming administration. It would appear, therefore, that we may look forward to the appointment of these Committees in the near future.

FINANCES.

Financial Condition Satisfactory.—As this subject will be dealt with in detail in the reports of the Treasurer and of the Finance Committee, only brief references will be made here. Last year there remained a surplus of $2,366.32. The Treasurer's report for the present year shows this surplus increased by $482.28, giving a total surplus of $2,848.60 now on hand, of which approximately $2,000 are conservatively invested in railroad bonds. In view of the fact that the expenses of the General Office have been considerably increased, and that a contribution for the year is very gratifying. We have not yet quite attained that ideal condition laid down by Past President Marks in which members' dues would entirely cover the expenses of the Society, while all income from advertising in the TRANSACTIONS could be devoted to research or some kindred subject. It does not seem too much to expect that during the coming year this may be realized.

Annual Convention.

Convention Successful. Attendance Small.—The Convention, held this year in New York, N. Y., was very successful, although the attendance was small. The program was comprehensive and the papers in number and quality fully equalled the high standard set in the two previous conventions. As an adjunct to the Convention, a self-supporting exhibition of lighting appliances was made in an adjoining building. In conjunction with this exhibit there was an educational exhibit. The Convention itself and these exhibitions suffered in attendance by reason of the Hudson-Fulton Celebration then in progress. Neither the value of the proceedings nor the merits of the exhibitions should be judged by the attendance figures.

Expenses Met.—All expenses connected with the technical proceedings of the Convention, were borne by the Society. All entertainment and exhibition expenses were defrayed from generous contributions by manufacturing and lighting corporations, in particular by the lighting interests of New York City.

There has been same feeling that if in the future equally generous contributions were received, the effect might be to tempt to unduly lavish entertainment. This prompted the Council to adopt the following resolution:

Resolved, That, while the Council recognizes the indebtedness of the Society to the New England, Philadelphia, and New York Sections for the successful conduct of the three conventions that have been held, it is the opinion of the Council that, in holding future conventions, the amount of money which is raised by subscription, or otherwise, for purposes of entertainment, should be greatly restricted.

Technical Papers.

Popular versus Scientific Papers.—Every paper in presentation before this Society is thereby submitted for judgment to two tribunals; the one is the author's audience, the other is the entire membership of the Society and interested persons throughout the civilized world, who refer either to the papers in the Transactions or to reviews of the papers in the technical press. We must desire a favorable judgment from both tribunals and

since the second is much the larger and the more important, we must not fail to give it due emphasis in our consideration of the problem of the best character of papers for presentation before our Society. Undoubtedly papers dealing in an elementary manner with elementary subjects are of great value when presented from time to time before sectional meetings. It should suffice briefly to review such papers in the TRANSACTIONS. Undoubtedly also papers of great technical value, but of little interest to the majority of those who attend section meetings, will make their appearance from time to time. These may be reviewed very briefly before section meetings, but should appear in full in our TRANSACTIONS. It is submitted that it is a mistake to dispose of the latter class of papers by withholding them until the annual convention. Most papers of this character should be presented as soon as they are available.

Central Section Papers Committee Recommended.—There is reason to believe that the best policy which the sections could adopt would call for the presentation at each meeting of one popular paper and one paper of more advanced interest. This, however, would require for presentation as sections under the present arrangement, about 30 papers of each class per year, and it is obvious that at the present time this number of papers of merit is not available. This conditions suggests the adoption of some plan whereby papers would be procured by a central committee, perhaps with membership distributed among the various sections. In this way the most valuable papers could probably be secured and the average standard of the papers would be higher because a smaller number would be required, the various sections in many cases using the same papers. With such a committee studying to procure best available papers, and to have them presented in a suitable manner, it would be possible to present any suitable paper at all sections.

Written Discussions Desirable.—A good paper rarely receives the consideration and rarely brings out the discussion which it merits at any one section meeting. This is due largely to the small attendance at such meeting. It is suggested that an effort be made to develop written discussions of the various papers. This would become feasible if such a central committee were

to have all good papers printed in advance, and were to send them to a carefully considered list of members who are conversant with the subject dealt with, requesting that they attend one of the section meetings if possible, and if not, that they submit a written discussion. In this way the interest at our meetings could be enhanced by the reading of written discussions, and the value of our TRANSACTIONS would be greatly increased.

Resolution by Council.—In connection with the question of papers, the resolutions adopted by the Council during the year, and applying to papers are of value and are repeated here.

RESOLVED, That papers read before the Society shall be released by the Committee on Editing and Publication for publication by the technical press after presentation subject to the following conditions:—

That no paper is to be considered as presented until it has been approved by the Papers Committee.

That no paper is to be approved for publication until printed proofs have been subjected to the usual correction by the author and the Committee on Editing and Publication.

No paper of the Illuminating Engineering Society is to be reprinted for commercial advertising purposes, except by written permission of the Committee on Editing and Publication.

A periodical to be considered as belonging to the technical press must maintain a subscription list sufficient to permit it to obtain second-class postal rates.

Periodicals belonging to the technical press and answering the above description are to be given equal opportunity to reprint papers upon making written request to the Committee on Editing and Publication, and upon agreeing to state that the paper was presented before the Society.

That the Committee on Editing and Publication shall be authorized to copyright any or all papers presented before the Society, and that authors of papers shall be advised that the copyrighting of papers presented rests with the Society, and that the copyright shall belong to the Society.

The following list of requirements in regard to technical papers of the Society was approved by the Council:—

Papers must be submitted four weeks prior to the date of

meeting, in order to insure their presentation and to permit of the printing of advance copies.

The Papers Committee, at its discretion, is at liberty to accept papers for reading before section meetings, with the understanding that the papers are not to be reproduced in the TRANSACTIONS. Likewise the Committee may accept for reproduction in the TRANSACTIONS, papers which are presented at technical meetings by title only.

No matter in which the advertising feature has undue prominence, is admissible.

Papers descriptive of lighting installations, when such installations contain no new features, and when the papers contain no new and valuable data, are not desirable matter for the TRANSACTIONS.

Previous general publication bars matter from the TRANSACTIONS, except that the Papers and Editing Committees are at liberty to depart from this rule when matter of special value is presented.

Cost discussions are acceptable only when the discussion is limited to a single type of illuminant in any one paper.

The title of a paper should be reasonably indicative of the subject of the paper.

Trade names should not be used in technical papers.

Discussions should be governed by similar rules, as far as they are applicable.

A lecture or an address may be delivered before the General Society by request of the Papers Committee or before a Section by the request of the Section Board of Managers.

THE SOCIETY'S FUNCTIONS.

Society's Name.—When this Society was organized, the selection of a name formed a subject of much thought and discussion. Very wisely, those directing the movement avoided the name Society of Illuminating Engineers. It is doubtful if the name finally selected could have been, or could now be, improved upon. However, it was, and still is, somewhat of a misnomer. The record of the activities of the past four years and the character of the papers included in our TRANSACTIONS, demonstrate that the attention of the membership has been distributed wide-

ly among a great variety of matters relating more or less closely to the subject of illumination. Illuminating engineering proper has occupied too small a part of the Society's attention to warrant the prominence given it in the Society's name. To some slight extent the Society has suffered from a misunderstanding arising from a misinterpretation of its aims, due to its name.

Relations with Illuminating Engineering Profession.—There is developing a degree of uncertainty as to the precise function or functions which this Society is expected to serve. Some day in the not far distant future, the Society may have to answer for itself whether it is primarily an exponent of that specialty which has become known as Illuminating Engineering, or is primarily a Society for the study and improvement of the art and science of illumination.

Educational Work by Society.—At this time there is an insistent demand that the Society undertake educational work pertinent to illuminating engineering. From all the sections one hears requests for elementary papers dealing with the fundamentals. Undoubtedly the Society can be of much value along some such lines and it would appear timely to consider the desirability of undertaking this work. All the work of the Society is in a sense, educational, but in this case the demand is that section meetings be given over to talks on the elementary phases of illuminating engineering. This presupposes a considerable class of members or prospective members, who desire instruction in these matters, but who are not prepared to obtain it from available text-books or magazines, or Society TRANSACTIONS. The demand for such work will probably be met in some of the sections.

PROPOSED COMMITTEE ON PROGRESS.

Committee on Progress Suggested.—It appears desirable for the Society to so faithfully record progress in the field of illumination that our TRANSACTIONS shall become a history of the art. This thought suggests the recommendation that the incoming administration appoint a Committee on Progress to submit to the annual convention a review of the progress of the year then past.

General Office.

The Society suffered during the year the loss of its Assistant Secretary, Miss Westervelt, whose health had been failing for some time prior to her resignation in the late spring. In passing, it will be a pleasure to members to note that Miss Westervelt's health is improved and is nearly normal.

The services of Mr. Frank D. Shea as Assistant Secretary were secured in August, and he is now in charge of the general office. During the year, the duties of Assistant Secretary have been enlarged by the keeping of the Society's accounts and by the reporting of the annual convention and the New York Section meetings, as well as various committee meetings. A larger office in a more pleasant quarter of the United Engineering Societies Building has been procured and auxiliary storage space has also been made available for our use. The Society has purchased during the year, additional furniture, including a director's table, rug, chairs, etc.

With this new office available, we are no longer forced to accept the loan of a sister society's office for Council and Committee meetings.

Summary.

The year's developments, taken in conjunction with the records of the three preceding years, indicate that our Society has a real and distinct field of enterprise; that its organization has been justified by its accomplishments; that much has been accomplished which without it would probably have remained undone; and that the Illuminating Engineering Society is not one of the unnecessary and superfluous societies. The lighting industry really needs an organization such as ours.

If these things be true, there is required only wise administration of our affairs to make the Society a power for good.

Respectfully submitted,

PRESTON S. MILLAR, *Gen. Sec'y.*

NEW YORK SECTION.

MEETING OF DECEMBER 17, 1909.

Held in conjunction with the National Commercial Gas Assn. in the Concert Hall of Madison Square Garden.

Chairman Elliott presiding.

The Chairman:—When the first movement was made toward the organization of the Illuminating Engineering Society the question was seriously asked. What would become of the feeling of competition between the two great lighting interests—gas and electricity?—would it be possible to harmonize those so that they could work side by side in a single organization?

The meeting to-night, which is a joint meeting of the New York Section of the Illuminating Engineering Society and the National Commercial Gas Association, is an answer to that inquiry. It is one of the characteristics, I believe—and a fortunate one—of the American, that he seldom lets competition interfere with friendly relations and legitimate business methods. So far as this organization is concerned, its one purpose—its only purpose—is to promote a better use of light, and that works to the interests of the public in general and to everyone who is serving that public in the capacity of a purveyor of illuminants. The success of that organization, as well as of the Association with which we are jointly holding the meeting, is a sufficient evidence of the fact that I have stated.

The first paper of the evening will be on street lighting fixtures, illustrated with stereopticon views, by Mr. H. Thurston Owens.

The Chairman:—We will defer discussion of this paper until after the presentation of the second paper of the evening, which will be on the subject of "Modern Gas Lighting in the Home, Store and Office," by Messrs. Lansingh and Rowe, to be presented by Mr. Rowe.

STREET LIGHTING FIXTURES.

BY H. THURSTON OWENS.

Art in street or public lighting fixtures is not an engineering but rather an architectural problem, but it has not been handled as such in this country. While the author agrees most heartily that we need the aid of the artist-architect in the design of the fixtures themselves, no one is in better position to bring about a general interest in the subject than the engineer.

Attractive public lighting fixtures are an asset of no mean importance to both the company supplying the light and the community served. There is no surer way of demonstrating the desire of a company to supply adequate service than to maintain the public lighting equipment in an attractive as well as an efficient manner.

If any one considers this a mere theoretical exposition let him investigate the service received by the consumers in a city where public lighting fixtures are a delight to the eye with the conditions in a city where the fixtures are an eyesore.

When the cities of the old World with their wealth of art treasures and historical monuments consider it good business to spend thousands where we sometimes spend hundreds, surely this is not an abstract subject, but rather a live question of no mean importance.

The history of the great luminants, gas and electricity, began with public lighting. Gas was first introduced on London Bridge in 1807, and electric arc lamps were first installed upon Avenue de L'Opera, Paris, in 1878, both being used later for indoor lighting. What is true of the original lamps using either gas or current is true of the later types, recent examples being the high pressure gas lamps and flaming arc lamps.

Although it may be interesting to prophesy as to the lamps which will light our homes by considering their application for exterior illumination, the basis upon which the illumination is purchased is of far greater importance.

Street lighting contracts are based upon service, not upon so

many cubic feet, watts or candle-power. They are flat contracts for so much illumination, whether it is measured illumination or not. Selling illumination in our buildings means selling service and service means maintenance. The practicing Illuminating Engineers in embryo ar the employees of the great corporations which not only sell cubic feet of gas or kilo-watts of current, but also maintain the consumers' lamps just as they do those lighting the public highways.

Service is what the public want in their homes, factories and workshops, it is what they pay for, and the successful company is the one which endeavors to supply this demand.

MODERN GAS LIGHTING IN THE STORE, OFFICE AND HOME.

BY VAN RENSSELAER LANSINGH AND EDWARD B. ROWE.

Progress and Publicity are the passwords to continued success for any producer. Either of the two without the other means only partial returns, while the two together re-act to promote each other and the effect on returns is cumulative. Progress is here intended to mean successive advances in the efficiency or quality of method, material or article, and Publicity might be defined as the honest exploitation of such advances between producers and to consumers. There can be no disputing the fact that during the last five years marked progress has been made in the methods, materials and appliances connected with the production and utilization of artificial light.

Much of the credit for this advance is due to the Illuminating Engineering Society, first, because it makes possible the free exchange among physicists and engineers of the results of investigations and experiments and the fundamental data on which real improvement must be based, and second, because its deliberations and discussions have forced those interested in or connected with the lighting game to realize the importance of this fundamental engineering data. Furthermore, it has brought together many allied interests which are all closely connected with the subject of artificial lighting and thereby give a publicity to the diversified phases of the subject which would not otherwise have occurred. This has all tended toward a better understanding of the problems connected with artificial illumination, and in a measure has educated the general public to appreciate and demand better illumination, not only in our streets and stores, but in our public buildings, offices and homes.

Many of us have failed to realize to what an extent this public education and advance in the art is due to commercial organization, either associations or independent business concerns, particularly to their publicity work. The National Commercial Gas Association and the National Electric Light Association are

really doing just as much good work in the world as the American Gas Institute and the American Institute of Electrical Engineers, for after all, the ultimate object of human thought and effort is to benefit mankind and this is mostly accomplished by material things. Hence our yearly Electrical Shows and Gas Exhibitions, by showing the constant improvement in electric and gas appliances are doing their part in this education of the public.

Improvements and changes are so rapid and the shows and exhibitions reach such a very small part of the general public that recently the Gas and Electric Companies have adopted other methods of keeping their customers constantly informed of the march of improvement. By means of demonstration and display rooms the various applications of gas and electricity for light, heat and power are shown, and the construction and operation of the appliances clearly and convincingly explained. Questions pertaining to lighting, however, cannot be fully answered by the exhibition of a light unit with a statement as to its cost of operation and illuminating efficiency, since so many other conditions influence the effect created and the satisfaction obtained in any given case.

Realizing this fact, several companies have put in typical lighting installations to show what can be accomplished with up-to-date equipment, and one company is so thoroughly convinced of the value of such installations in educating its consumers and the general public to appreciate the results which can be obtained if the equipment is correctly designed and located for the purpose it is to serve, that an entire building is being used to illustrate by examples the modern ways of lighting the store, office and home

The progressive company to adopt this form of educational publicity is the Consolidated Gas Company of New York. During the early part of this year, the four-story and basement building at No. 29 East 21st Street, New York, was acquired to serve as display rooms for the numerous gas appliances on the market, and to contain also a model apartment, a full-size exhibition of what could be accomplished by gas for lighting, heating and cooking in the home. As the upper floors are devoted to general office work, an opportunity was presented of combining

in the one building, examples of display window, store, office and home lighting. The plan was conceived by Mr. Walter R Addicks and has been carried to a successful completion under his direction. The immediate supervision of the work was under Mr. H. B. McLean in charge of the Appliance Department. Mr. H. J. Hardenberg was the architect and Mr. V. R. Lansingh the Consulting Illuminating Engineer for the company. Fig. 1

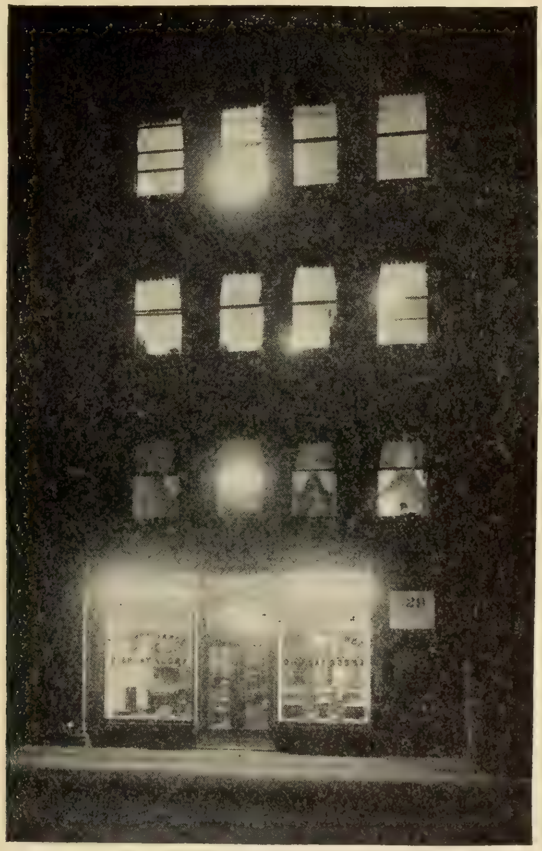


Fig. 1.

shows the exterior appearance of the front of the building at night, that is, from directly across the street. Approaching along 21st St., or even passing on Broadway, one's attention is forcibly drawn to the building by a huge flashing electric sign, indistinctly shown, which extends from the second floor to the roof. The most noticeable thing in the photograph is the blaze of light in the windows, the lighting equipment of which consists of 12 outlets in each window, at present with a single reflex lamp at

each outlet with satin finish Holophane distributing reflector and clear inner cylinder. Reflectors of the concentrating type would increase materially the already very high intensity on the goods displayed. As the window displays will be made up entirely of gas stoves, heaters and similar appliances, the light absorption is high and a maximum intensity is required.

To determine the actual foot-candle intensity on the floor of

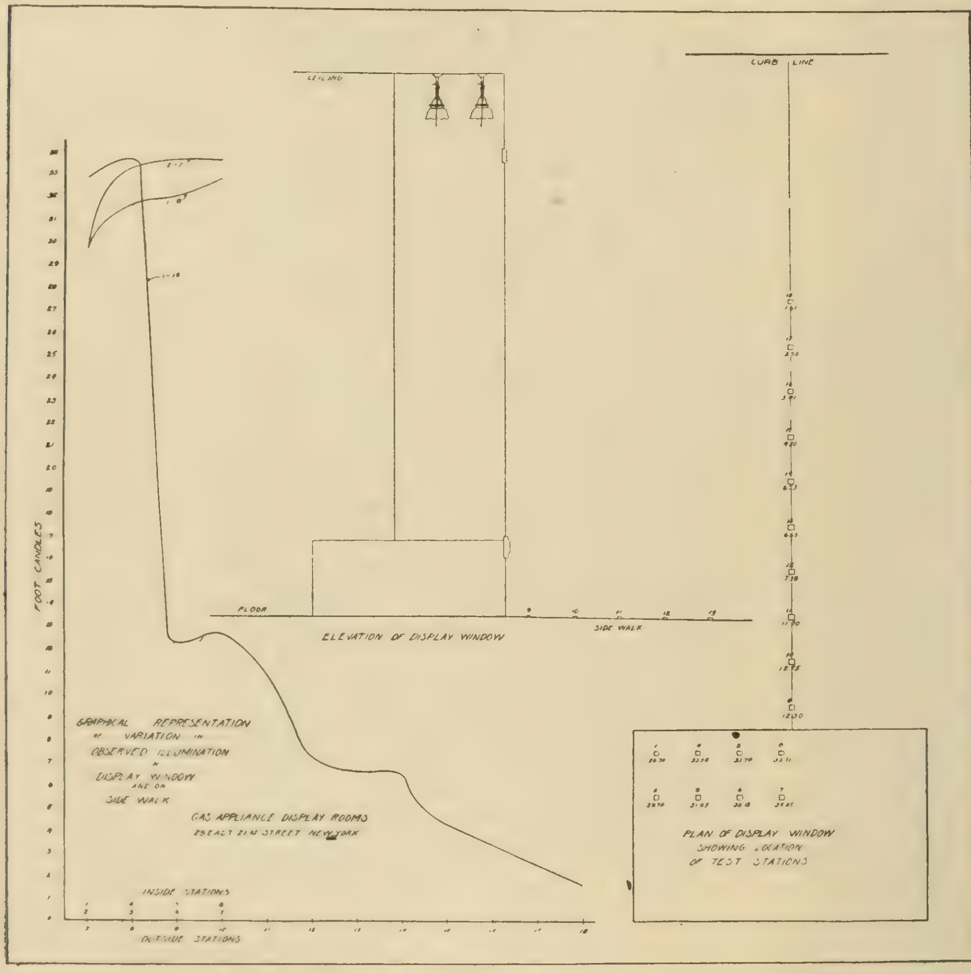


Fig. 2.

the window, an illuminometer test was made on the evening of December 8th, readings being taken at the stations as shown on plan (Fig. 2) which gives also the elevation of window and a graphical representation of the foot-candle intensities obtained. It should be stated here that the illuminometer and other instruments used in this test, and the others made on the same even-

ing, were calibrated at the Electrical Testing Laboratories the morning of the tests, and that no adjustment of burners for maximum incandescence, pressure, consumption, etc., were made, the lighting equipment in all parts of the building being in the normal operating condition in which it is kept by regular attendance and maintenance. The lighting system had been in operation for five months or more, and it can be assumed that the results here found will apply to any installation which is being regularly maintained. Pressures were measured by U-tube manometer and gas consumption taken from the meters installed—a separate meter being provided for each floor. A sufficient interval of time was taken on each test to allow readings to be taken with fair accuracy.

In addition to the illumination values obtained in the window several readings were made outside the window on the sidewalk on the same plane as inside at one foot intervals as indicated on the plan.

OBSERVED HORIZONTAL ILLUMINATION VALUES. DISPLAY WINDOW AND SIDEWALK.

Inside Window Station	Foot-candles	Outside Window Station	Foot-candles
1	29.7	9	12.3
2	29.7	10	12.8
3	31.7	11	11.0
4	33.4	12	7.4
5	33.7	13	6.7
6	32.1	14	6.5
7	32.9	15	4.3
8	33.7	16	3.4
		17	2.5
		18	1.6

SUPPLEMENTARY DATA.

Height window floor to ceiling, 10 ft. 2 in.
Height to mantles, 8 ft. 10 in.
Height to test-plate, 6⅝ in.
Height of mantles above test-plate, 8 ft. 3⅜ in.
Number of outlets, 12.
Number of burners per outlet, 1.
Total number of burners, 12.
Total gas consumption, cu. ft. per hr., 40 (estimated).
Number of test-stations, 8.
Average foot-candles, inside, 32.1.
Average foot-candles, outside, 6.8.

It will be noted that the intensity curve falls rapidly as we pass from one side of the front glass to the other, due to direct reflection from inside of glass, but with concentrating reflectors in place of the present distributors the slope of the curve will undoubtedly be even more abrupt.

Turning now to the interior of the store (Fig. 3) one is immediately impressed with the complete and attractively arranged display of the innumerable gas appliances which are now available

Fig. 3.

for domestic use. The stoves and ranges are placed along the sides of the room, with the smaller articles on tables at the rear.

As it was necessary with such dark goods displayed, the color scheme is light, side walls straw and ceiling white. Owing to the extreme length of the room, and the consequent poor daylight illumination at the middle, some artificial light is necessary the greater part of the time, and the illumination from the four-light gas fixtures seems to blend perfectly with the daylight illumina-

tion from the windows. The fixture used on this floor(Fig. 4) is a special eight-light combination, four gas and four electric. Note particularly the similar treatment of the gas and electric outlets—the gas equipment being the reflex lamp with Holophane satin finish distributing reflector and clear inner cylinder, while the electric equipment consists of bowl-frosted 40 watt tungsten lamps and the same distributing reflector.

There is a certain popular preference for gas lighting in the

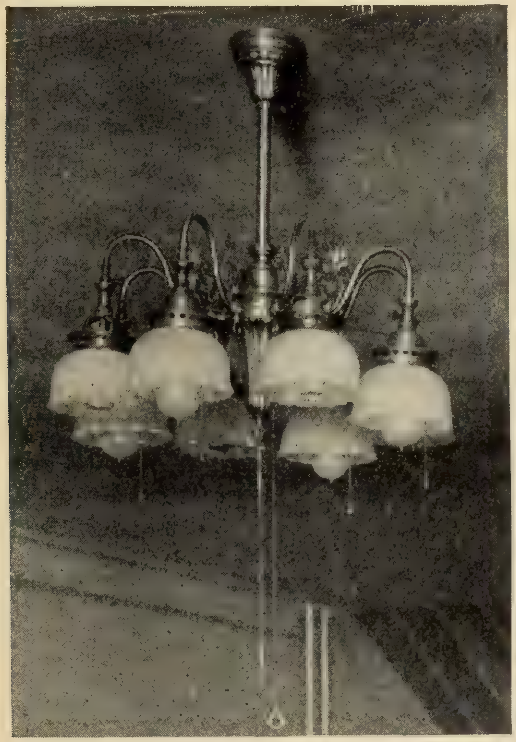


Fig. 4.

winter and electric lighting in the summer. The usual practice in such cases is to employ separate outlets and equipments that do not harmonize in the least and serve to give the impression of a room full of lighting fixtures. Combination fixtures of the kind illustrated here, besides being a well-balanced harmonious whole, also gives the maximum attainable efficiency of both illuminants, with a considerable range in the choice of glassware available. This is just as true of fixtures for upright gas and

electric equipment, except that the maximum attainable efficiency, meaning by that the lumens on the desk plane per cu. ft. of gas per hr. or per watt, is somewhat less than for pendant units. This is due to the practical impossibility of designing glassware whose re-direction will fully compensate for the loss of light caused by supporting the light source and glass ware from below. To obtain certain desired effects, however, this slight loss, and even a very considerable loss, is often warranted.

This seems to be a particularly good opportunity to call attention to the great similarity of the two light units on this fixture from the customer's standpoint. The sources of light are both cylindrical in shape, of approximately the same outline dimensions, enclosed in glass bulbs and supported from a holder or socket. Both can be lighted by the pull of a chain, or a push on a button, and extinguished in the same way. The same types and kinds of glassware can be used with both and similar distributions obtained. When they burn out, the source is thrown away and a new one purchased by the consumer, or in the case of carbon lamps, supplied by the company which furnishes energy for the lights. The new gas mantle of course must be adjusted for maximum incandescence but this is comparable in a way to selection for average voltage in the case of electric units and satisfactory operation is dependent on this adjustment or selection in either case.

Fig. 5 shows the general shape of the street floor and the location of outlets and test stations. A graphical representation of the variation in foot-candle intensity obtained is shown in Fig. 14—the results of the test are as follows:—

OBSERVED HORIZONTAL ILLUMINATION VALUES FIRST FLOOR.

Line 1-9 Station	Foot-candles	Line 2-10 Station	Foot-candles
1	1.55	2	3.03
4	2.91	3	7.18
5	3.26	6	6.23
8	3.62	7	7.74
9	3.60	10	7.32

SUPPLEMENTARY DATA.

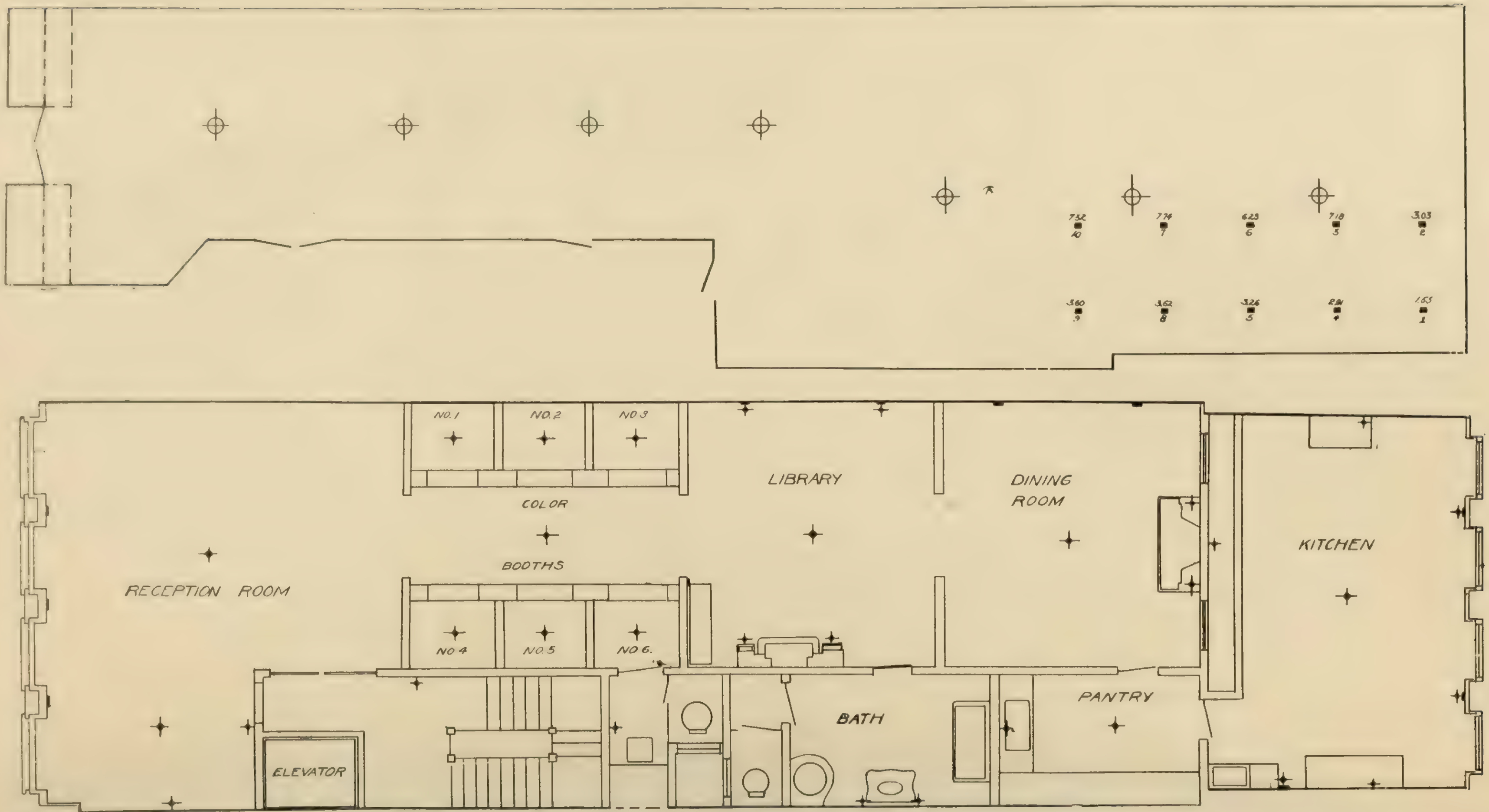
Maximum dimensions of room, 91 ft. x 23 ft.
Height to ceiling, 12 ft. x 0 in.
Height to mantles, 10 ft. x 0 in.
Height to test-plate, 2 ft. x 9 in.
Height of mantles above test-plate, 7 ft. x 3 in.
Number of outlets, 7.
Number of burners per outlet, 4.
Total number of burners, 28.
Total gas consumption, cu. ft. per hr., 93.
Average consumption per burner, 3.3.
Pressure, inches of water, 1.5.
Total area of floor, sq. ft., 1745.
Cu. ft. of gas per sq. ft., 0.053.
Number of test-stations, 10.
Average foot-candles, 4.64.
Lumens per cu. ft. of gas, 87.5.

The efficiency therefore checks very closely with previous determinations on similar installations.

We come now to the Model Apartment, the general arrangement of which is shown in Fig. 5. A very unique daylight effect is obtained in the dining room, the two windows being boxed in and the interior of the space being painted a matte white. Three standard upright mantle burners are placed between the windows as indicated and controlled by pneumatic buttons located side of windows. Pink Rambler roses cover a trellis just outside the window and the deception is quite successful.

Stepping out of the elevator we enter the reception room. In one corner is located the telephone exchange and in addition to this convenience there will be found writing materials, current literature, etc., and comfortable chairs while resting or awaiting friends. The color scheme in this room is a dark green, the walls, wicker furniture and carpet being of this shade with the door and window trim and ceiling in white. The lighting equipment consists of one eight light and one two light fixture and two one light side brackets, all with inverted mantle burners and art glass globes. Several baseboard outlets are also provided.

In the reception room near the telephone exchange is located a new portable form of instrument for color comparison under different illuminants. This has been called a "sochrodometer," a



NO. 1
NO. 2
NO. 3
COLOR
BOOTHS
NO 4
NO. 5
NO 6.
RECEPTION ROOM
LIBRARY
DINING ROOM
KITCHEN
PANTRY
BATH
ELEVATOR

Fig. 5.

word derived from solar (relating to the sun), chromatic (pertaining to color) pseudo (signifying false) and comparimeter, therefore meaning *false comparison of sun colors.* Either end of the instrument can be placed against a window to obtain the daylight standard, and the colors travel through the successive compartments on an endless belt. Provision is made for attaching to this belt any fabric or color which a visitor may wish to try under any particular illuminant, or to compare under the different illuminants. The form of the sochrodometer is shown in Fig. 6.

Fig. 6.

Between the reception room and library on either side of the passage are located booths or small rooms for demonstrating the great effect of color of walls on the illumination on any given plane produced by any given light unit. The illustration, Fig. 7, shows the three booths on one side but the actual difference is much greater than is apparent in the photograph. Each booth is lighted by one inverted mantle burner with clear distributing

reflector and clear cylinder in the center of the ceiling. Control is pneumatic from push botton on wall. The curtains for the booths are all faced on the inside with material of the same shade

Fig. 7.

as the wall paper, and the colors adopted for the latter are as follows:

No. 1 Salomn	No. 3 Cream	No. 5 Blue
No. 2 Red	No. 4 Green	No. 6 Cream

The wall papers are of very nearly the same texture and any difference in the illumination obtained can be considered as due to absorption by color alone. Readings were taken in each of the Booths 1 to 5 to obtain some comparative figures for this absorption. In each booth the mantle was adjusted to give as nearly as possible the same candle-power value directly below the center of lamp, as measured by the illuminometer used as a photometer. Since the equipment was the same in all the booths, the distri bution and total flux of light would be approximately the same

when the candle-powers at any one angle were equal. Then with the illuminometer disc 2′ 6″ from the floor, foot-candle values were obtained at the point directly beneath the lamp as follows:

No.	Color	Foot-candles	Per cent. of No. 1
1	Salmon	3.34	100
2	Red	1.87	56
3	Cream	2.93	88
4	Green	1.67	50
5	Blue	2.36	71

Not only does the intensity vary greatly with the color of the paper but the character of the reflected light is quite different. This was very noticeable in making the illuminometer settings where the color of the two fields in the prism varied greatly in the different booths. It may be interesting to note here that very nearly a perfect color match was obtained in the test in Booth No. 1, which showed the highest foot-candle reading. In a measure these readings, as are all illuminometer readings in fact, are only indicative, since so much depends on the personal equation in setting for a color match rather than for intensity, a matter which received attention in Mr. P. S. Millar's recent I. E. S. paper on "Heterochrome Photometry." The question of light absorption by color and its effect on efficiency, as well as its physiological and psychological importance, certainly justify the illustration and explanation of these color effects to the general public and the method of accomplishing this which is here illustrated deserves very favorable comment. The effect of different illuminants on the same colors has been repeatedly demonstrated but this is the first instance that we know of where the effect of *one* illuminant on *different* colors has been given prominence.

We pass now to the Library, (Fig. 8) a room richly and appropriately furnished and decorated. The furniture is in old English oak, as is also the wall panelling and the beautifully carved mantle. The latter deserves particular comment—it is Elizabethan in style, as is the whole room, and was designed and executed especially for this room under the supervision of Mr. Hunting of Mr. H. J. Hardenberg's office; it emphasizes the great expenditure of both time and money that has been made to have this model apartment second only to the ideal.

The lighting fixtures were all designed for the room and are very well illustrated in the photograph. On the mantle are two small standards—quite a departure from the customary side brackets—equipped with small upright mantles completely concealed by amber glass set in hammered bronze. The table portable shown at the left is a larger edition of the mantle fixtures, with a standard upright mantle. The center dome is not only

Fig. 8.

very attractive but performs its lighting functions quite efficiently. The gas is brought into the dome through one of the supporting rods and fed to a standard inverted mantle burner equipped with distributing reflector, which while allowing sufficient light to pass through to illuminate the amber glass, redirects most of the light uniformly over the ground glass plate closing the bottom of the dome. Glare is therefore entirely eliminated and at the same time the required reading intensity is provided at any part of the table.

In the center of the photograph may be noticed a specially designed bookcase portable. Such a lamp could be used as a piano lamp or for similar purposes. The same shade without the base is used in this room for the side brackets—which do not appear in the photograph. Baseboard outlets are provided for other portables.

Adjoining the library is the bath room, done in tile and marble, with porcelain and nickel fittings. The light units are placed one on either side of the mirror, and consist of Welsbach

Fig. 9.

"Junior" mantle burners with Holophane upright globe No. 2404 on nickel fixtures. The diffusion is such that glare is entirely eliminated, and the distribution, combined with the high reflection from the walls, etc., of the room, give altogether satisfactory results.

After admiring the bath, we go back through the library into the dining room. Fig. 9 shows the daylight effect which was mentioned at the time the plan of the apartment floor was given.

The true effect must be seen to be fully appreciated however. In the dining room the design is colonial, the wall paper and rug being in blue and the woodwork white, with the furniture of mahogany. The single lamp brackets are from the "lamp" motif, the chief feature of lighting in the Colonial period, while the dome is also a Colonial adaption. A recent issue (December) of the *New York Illuminating Engineer* has to say on this subject—"To preserve the atmosphere of Colonial times not only must the structural features faithfully express the architectural types of those days, but the furnishings, including the lighting fixtures, likewise follow the prevailing taste of the same period The methods of illumination at that time were oil lamps and candles. The former made use of the glass shade, and for decoration glass prisms and jewels were the common means employed." In each side bracket one, and in the dome four, junior upright mantles are used.

Several baseboard outlets are provided for the chafing dishes and percolators, the method of attachment being shown in the photograph.

We pass from the dining room through the pantry to the kitchen, the only features of the pantry lighting deserving special comment being the small inverted mantle burner over the sink, where good light is quite essential. A standard upright mantle with opal dome and bobesche is provided for the general illumination.

The same provision is made in the kitchen, a standard mantle, inverted, with opal cone shade being placed near the sink, and also a baseboard outlet, from which the adjustable bracket outlet under the hood of the range is fed. Similar equipment is provided for the other range (Fig. 10) and over the small tables in the room. The central ceiling outlet is equipped with a two light reflexolier, with satin finish Holophane distributing reflectors. A relatively large number of outlets in the kitchen seems to be justified when we consider that it is here that our food is prepared. Unclean food or plates served in the dining room would certainly not pass unnoticed. Why not then provide an abundance of light in the kitchen properly distributed where it is most needed, so that such occurrences will be prevented? Such

a procedure seems perfectly logical and yet the kitchen lighting is far too often left to a single ceiling outlet, generally improperly equipped.

Desk lighting is still one of the unsolved problems of illuminating engineering; meaning by that, that there is no one standard method which is universally satisfactory.

The individual lighting of each desk was for a number of years,

Fig. 10.

and still is, to a certain extent—quite satisfactory, but it is a method which has numerous serious objections—particularly from the gas-man's point of view. There has been developed recently, however, an electric equipment which has been shown by numerous tests to satisfactorily replace the individual desk lamps and which overcomes many of the objections to the latter. This has been called a "distributed unit system," and the illustration (Fig. 11) shows what is undoubtedly the first installation of such a system, using gas. Numerous difficulties had to be

overcome in this particular instance before it was certain that the proposed equipment could be put in. The greatest of these difficulties was the impossibility of running piping between the ceiling and floor above, making it necessary to use the old ceiling outlets. Mr. Addicks conceived the idea of forming panels on the ceiling to score the ceiling slightly for the pipes and conceal these in wooden molding connecting the proposed outlets and

Fig. 11.

forming the panels. This was done, the molding shown in cross-section on the plan (Fig. 12) being designed to harmonize with the border molding of the room.

Twenty-six outlets were provided as shown in the plan and each is equipped with a single Welsbach reflex lamp and Holophane satin finish distributing reflector No. 6321 with clear inner cylinders. Pneumatic control from wall buttons is provided and has proved to be positive and reliable in service, with practically no attention required after it is once adjusted properly provided it is not attempted to control too many lights from one button.

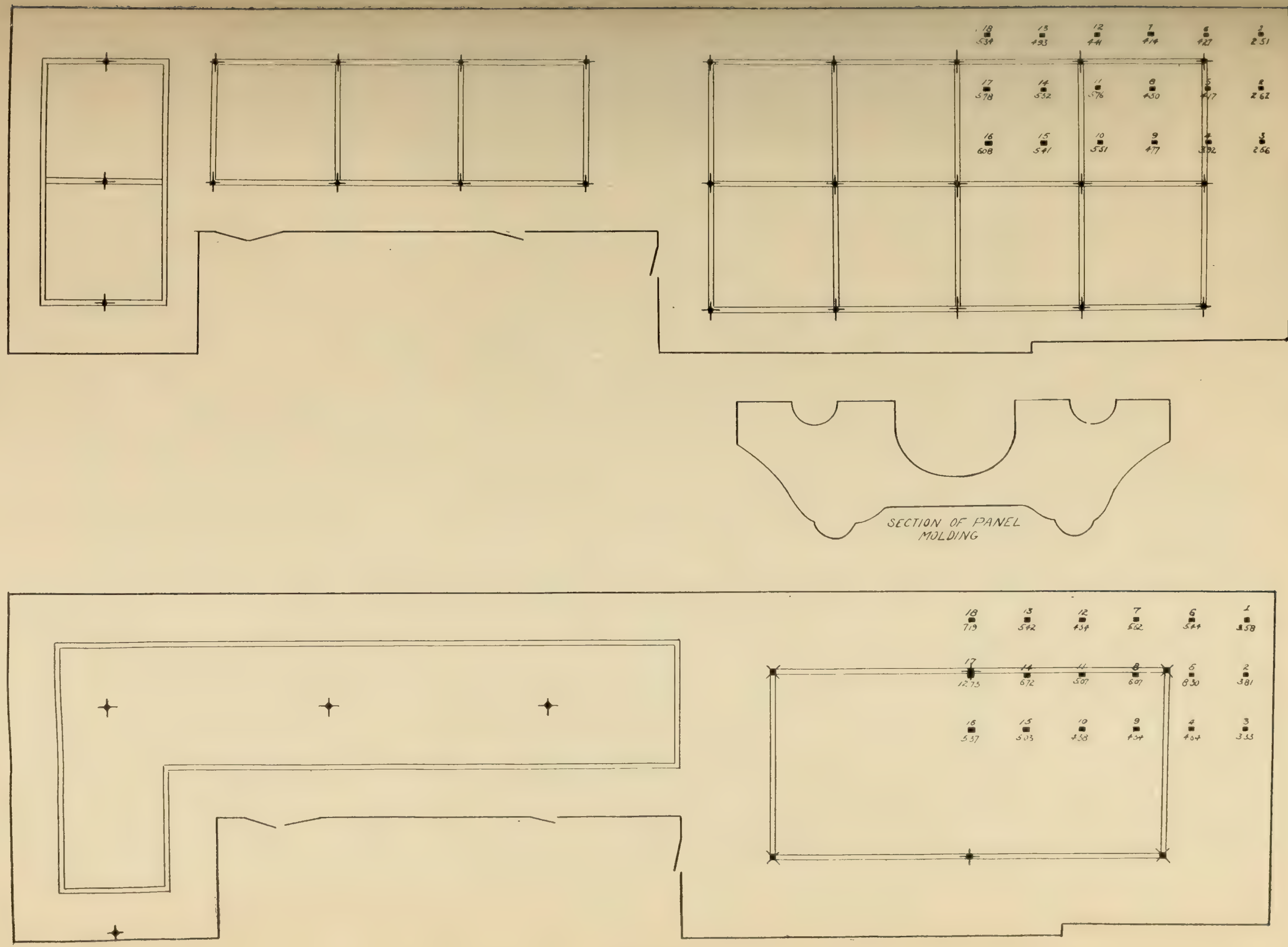


Fig. 12.

On this floor the outlets are controlled in threes in the rear of the room and in twos at the front.

To determine the illuminating efficiency of this type of equipment, readings were taken at the 18 stations shown on plan, it being assumed that the average of these stations would give a fair average for the entire room.

OBSERVED HORIZONTAL ILLUMINATION VALUES. THIRD FLOOR.

Line 1—18		Line 2—12		Line 3—16	
Station	Foot-candles	Station	Foot-candles	Station	Foot-candles
1	2.51	2	2.62	3	2.56
6	4.27	5	4.17	4	3.92
7	4.14	8	4.50	9	4.77
12	4.41	11	5.78	10	5.51
13	4.93	14	5.52	15	5.41
18	5.34	17	5.78	16	5.08

SUPPLEMENTARY DATA.

Maximum dimensions of room, 84 ft x 22 ft.
Height to ceiling, 10 ft. 2 in.
Height to mantles, 8 ft. 7 in.
Height to test-plate, 2 ft. 9 in.
Height of mantles above test-plate, 5 ft. 10 in.
Number of outlets, 26.
Number of burners per outlet, 1.
Total number of burners, 26.
Total gas consumption, cu. ft. per hr., 83.4.
Average consumption per burner, 3.2.
Pressure, inches of water, 1.6.
Total area of floor, sq. ft., 1,680.
Cu. ft. of gas per sq. ft., 0.05.
Number of test stations, 18.
Average foot-candles, 4.57.
Lumens per cu. ft. of gas, 92.1.

The illumination efficiency agrees well with the constants derived from similar installations and the illumination, it will be noted, is quite uniform, the maximum deviation from the mean, which occurs at Station No. 1 in the corner, being only 45 per cent. It is interesting to notice in the photograph of the office floor, the manner in which the illumination gradually and uniformly drops off from the floor, up the side walls to the ceiling.

Comparing this with the photograph (Fig. 13) of the floor above, the difference is very marked—note the spotted effect on floor, walls, and ceiling on the fourth floor. The equipment here is a four light reflexolier with opaline balls, the outlets being located as shown on plan, Fig. 12. In the illuminometer test

Fig. 13.

on this floor the same test stations were used as on the office floor below. The results of this test are as follows:—

OBSERVED HORIZONTAL ILLUMINATION VALUES. FOURTH FLOOR.

Line 1—18		Line 2—12		Line 3—16	
Station	Foot-candles	Station	Foot-candles	Station	Foot-candles
1	3.58	2	3.81	3	3.33
6	5.44	5	8.30	4	4.64
7	5.62	8	6.07	9	4.54
12	4.54	11	5.07	10	4.38
13	5.42	14	6.72	15	5.03
18	7.19	17	12.73	16	5.37

Supplementary Data.

Maximum dimensions of room, 84 ft. x 22 ft.
Height to ceiling, 10 ft. 2 in.
Height to mantles, 8 ft. 2 in.
Height to test-plate, 2 ft. 9 in.
Height of mantles above test-plate, 5 ft. 5 in.
Number of outlets, 9.
Number of burners per outlet, 4.
Total number of burners, 36.
Total gas consumption, cu. ft. per hour, 126.
Average consumption per burner, 3.5.
Pressure, inches of water, 2.2.
Total area of floor, sq. ft., 1,680.
Cu. ft. of gas per sq. ft., 0.075.
Number of test-stations, 18.
Average foot-candles, 5.65.
Lumens per cu. ft. of gas, 79.4.

Compared with the distributed unit system, this equipment

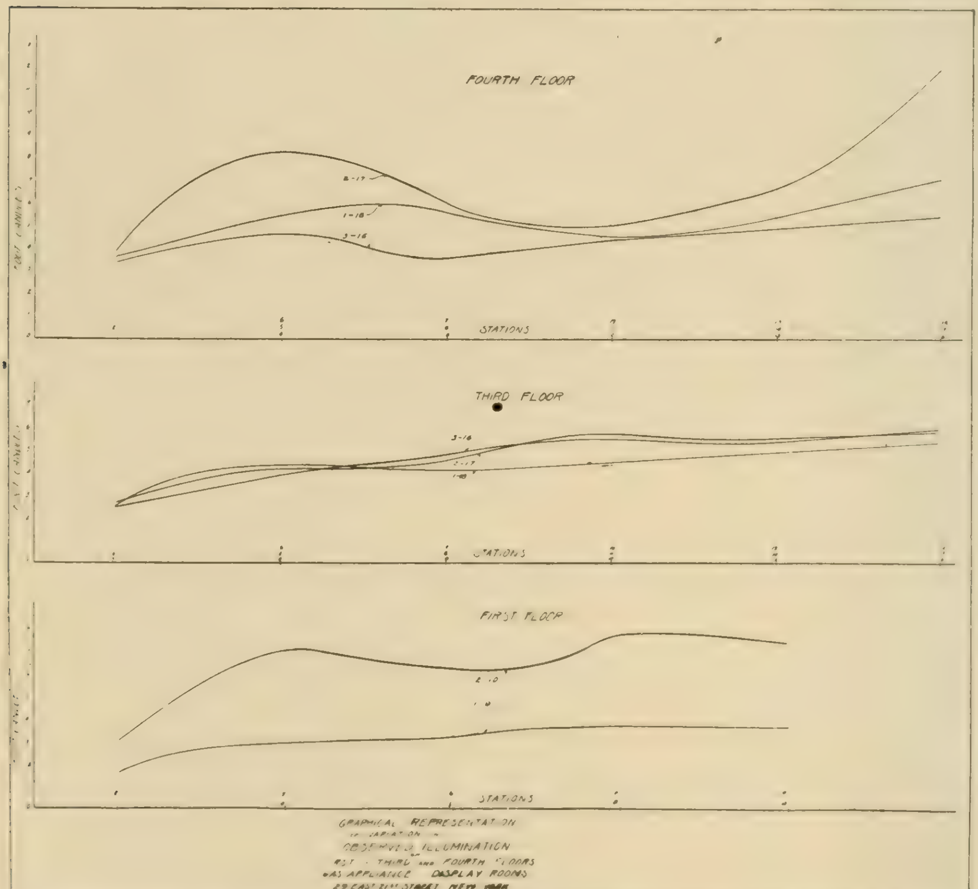


Fig. 14.

shows a maximum deviation at Station No. 17 of 125 per cent as

against 45 per cent., and as would be expected the lumens per cu. ft. per hour are much less,—79.4 as against 92.1. The pressure on the fourth floor it will be noted is 2.2 as against 1.6. However, the diffusion is as good with the opal one as with the satin finish Holophane.

Figure 14 shows the graphical representation of the variation in illumination on the first, third and fourth floors at the stations taken on these respective floors. The installation on the street floor was not designed for uniform illumination particularly, the old outlets being utilized. On the third or office floor, however, where uniformity was desired, the tests seem to show very satisfactory results. It might be stated that the bookkeepers on this floor who work by artificial light the greater part of the time have offered not a single objection to the system.

DISCUSSION

The Chairman:—Ladies and gentlemen, the two papers are now before the meeting for discussion. In opening the discussion I have the pleasure of calling on the President of the National Commercial Gas Association, Mr. Shattuck.

Mr. Shattuck:—These two papers are very interesting, but I did not come prepared to discuss them this evening. However, I think that the last paper is one that should be studied very carefully,—studied by all the gas men that are in New York, and they should make it a special part of their business to go there and see that building. I believe that there are a great many features that we should adopt in our home towns, and the one that appeals to me more than anything else is the model kitchen. The ordinary kitchen is not what it should be. It should be the best room in the house. It is, as a rule, the poorest room in the house.

In looking at these pictures, I do not believe that the light from the gas flame is going to be satisfactory. I think after two hours' cooking it will look rather sick. It is very seldom that you will see a kitchen properly illuminated with electric light or gas. It isn't long before the light is beclouded with fly specks and dirt, and it doesn't seem to get the proper attention. I think this educational work on the part of the Consolidated Gas Company in equipping this modern home is certainly an advance step in educational work. I hope that all present will discuss both of these papers.

The Chairman:—I do not know that I need call specifically upon anyone by name. There is certainly material in both of these papers for thought and reflection, and probably some difference of opinion. The papers are open for discussion now, if anyone wishes to take part.

Mr. Marshall:— I would like to call attention to one thing in this apartment. Heretofore the gas man has used the argument of cheapness of gas until that has become rather threadbare. I think that if any solicitor who uses that as his chief argument for lighting, will visit these rooms, he will come out with a very much greater appreciation of what may be accomplished in pleasant surroundings with gas. I have had the pleasure of visiting, probably, most every display room in the country, and I

have never seen any set of rooms so attractively furnished as these, and I would like to emphasize Mr. Shattuck's remarks about visiting these rooms to see what has been accomplished there.

Mr. Clark:—I would like to ask at what height above the floor the readings were taken. He has a value there of 4.57 foot-candles, but he does not state at what height that was taken—whether it was the height of the desk, which is the ordinary working height, or some other height. Another question that I would like to ask, as I shall not avail myself of the opportunity of visiting the Consolidated Gas Company's office just yet—I would like to ask about the ceiling in the rooms, that is, the rooms of different color—whether the ceiling is exactly similar—exactly the same as the wall paper, and how much difference that makes. It seems to me it would make considerable reflective difference in the blue room, for instance, with a ceiling of white. I suppose that the rooms must be blue throughout.

The Chairman:—I have not yet personally had the oppor-like to ask about the ceilings in the rooms, that is, the rooms of precautionary remark, probably that you are familiar with, and that is that it is a difficult matter to get good photographs of an entire shop where the rooms are somewhat limited in size, as these evidently were. A photograph is not always a good representation of things as they appear to the eye, as colors come in to vary the effects upon the photographic plate. I think that the slides shown, however, are a sufficient evidence to those that have not seen the rooms, that gas illumination in point of quality, both as regards the diffusion softness and pleasantness to the eye, can be made the equal of any illuminant. Certainly, the rooms shown are finely illuminated.

I quite agree with Mr. Shattuck's remark in regard to the illumination of the kitchen. There is a great tendency for us to neglect this important room of the house in the matter of illumination. The illumination here is apparently adequate at the present time, but we must always take into account deterioration.

Is there any further discussion?

Mr. Thompson:—What would be the proper height for an inverted burner?

Mr. Rowe:—Answering, first, Mr. Clark; I believe the question as to the height above the plane at which the illuminometer readings were taken, were the same on all floors, and were made at the 2 ft. 6 in. customary low desk level. To be sure, in the rear end of the office floor, where the bookkeepers' desks are located, that plane is probably on a 3 ft. 10 in. plane of these desks, but in order to have the readings uniform, they were taken at the 2 ft. 5 in. height.

So far as the colors of those ceilings are concerned, they are all white, if I am not mistaken. The point was brought out by Mr. Elliott that the photographs are not really indicative of the effect that is obtained there. Several of the photographs shown, particularly those which were repeated—the first slide where that was the case, was taken by the artificial light alone, as showing the effect obtained by the illumination. To a certain extent it does not do justice to the room at all. The second one did not do much better.

In speaking of the library dome, I neglected to give the equipment, which is a little different from customary practice. It is equipped with an inverted mantle burner, and at the bottom is placed a ground glass diffusing plate, the strong downward light from the mantle being nicely diffused, and while it illuminates the art glass in the dome, the maximum light is turned downward near the table for reading, and there is absolutely no glare.

Answering the last question of Mr. Thompson as to the proper height at which diffusing glassware should be placed; I am not quite certain in my mind as to what he means by "diffusing glassware." There are certain rules which have been given for different shapes of glassware. I think that light units should not be placed a distance apart greater than twice their height above the plane of the illuminometers, not very much over that distance. If so, the illumination will fall off and be spotted to a large extent. I think that covers the points that were raised.

Mr. Clark:—How much increase do you get from the 2 ft. 6 in. at the 3 ft. level, and what is the size now—the proper amount of illumination for office work? We find in different works by different writers a great variation, and I think, in all probability,

the Consolidated is in a position where it knows the proper amount of light to be given for office work. That is the first thing, I think, that should come under the notice of the illuminating engineer, and practically every new business man is called on to do a work—to work out photometric curves, and it makes a great deal of difference whether you want to get four candles or six.

Mr. Rowe:—As I said in the paper, desk lighting, or office lighting, is one of the biggest problems the illuminating engineer has to face, because, in that kind of work, the personal equation probably enters to a greater extent that it does anywhere else. I have found individuals who prefer entirely different kinds of lighting under exactly the same conditions; what would be entirely satisfactory to one would not satisfy the other; one would want a high intensity of light and the other a low intensity, and it can only be stated in general, that good desk illumination is from 3½ to 4½ foot-candles for close desk work. For clerical work, not requiring as fine work, for example, for a large room entirely equipped, say, with typewriters, a lower intensity would suffice, from 2¾ to 3½; but in all this the depreciation factor should be taken into account, and that is not usually done. We consider in laying out an installation merely the intensity and distribution that will be obtained at the time the installation is made. That, then, does not hold forever, and in similar types of installations it changes very rapidly, not so much in distribution as in intensity and that fact should be taken into consideration in designing and laying out installations.

The question of desk lighting and office lighting is a broad one, and there are a great number of individual opinions about it, and in a way, they are all right. As I said, I think a maximum of 4½ foot-candles, for most desk work, should be sufficient. However, the local lighting of a desk bracket, or portable, on the plane of the area at which the work is done, is usually very much higher than that, because a 16 c-p. lamp is very often placed in a concentrated reflector directly over the man's work, at an intensity, probably, of—well , I should not be surprised if it were between 10 and 15 foot-candles.

That raises another point about desk illumination. Personally,

I think that the most satisfactory equipment that I know of at present is from a single light suspended over the left hand side of the desk, a little over the end and over the front, equipped with a fairly concentrated reflector, so that the illumination is higher than at the other point. That gives a man a lamp illumination for ordinary work, and if he is trying to do some drawing, he can move over where the intensity is higher, but that is only applicable to individual lighting, and in large offices a great many additions are made, and where that is the case the distributive unit system seems to work out very satisfactorily.

PHILADELPHIA SECTION.

NOVEMBER MEETING.

SCIENTIFIC PRINCIPLES OF GLOBES AND REFLECTORS.

BY VAN RENSSELAER LANSINGH.
General Manager, Holophane Company.

Illuminating Engineering, while an extremely broad and somewhat ambiguous term, nevertheless has certain aspects of the subject which are well-defined, and more or less well understood. From a purely engineering standpoint, one of the most important parts of this subject is the redistribution of light

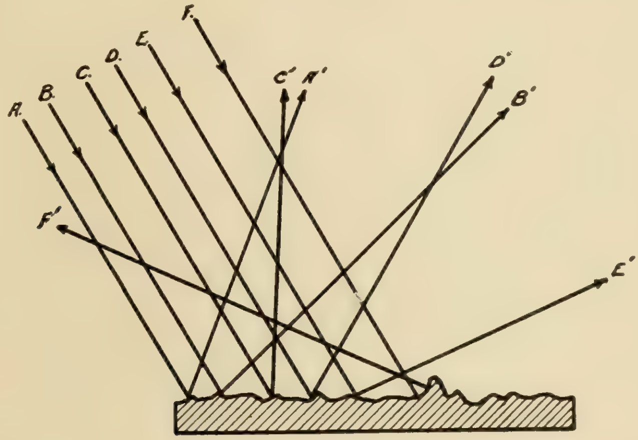


Fig. 1.

from any given light source. With the large number of different forms of light sources which are now commercially available, it is essential, in the majority of cases, to change the characteristic distribution of the source itself in certain ways so as to utilize more of the light flux than is possible with the natural distribution unchanged. This means that with modern light sources, it is usually necessary to redirect the rays, employing for this purpose globes, shades or reflectors. Therefore, the illuminating engineer must not only study carefully the means available for effecting this redistribution, but also he

should understand certain of the laws which make such redistribution possible and also the scope of their application in the present state of the art. Inasmuch as this subject is such a

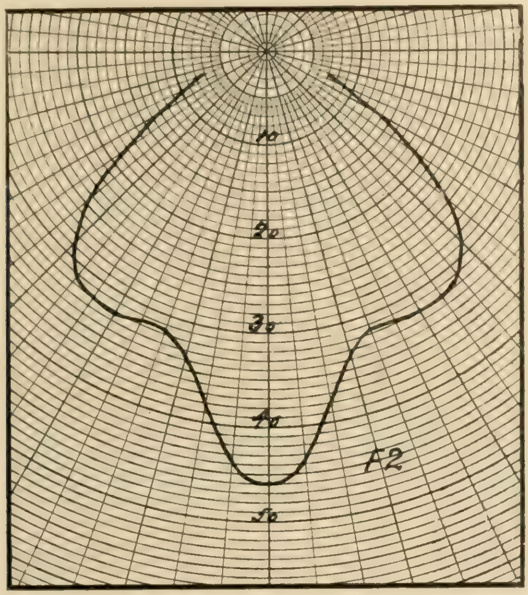


Fig. 2.

large one, it will be necessary in this paper to confine our attention entirely to the subject of redistribution of light derived from the modern electric incandescent lamp in its different

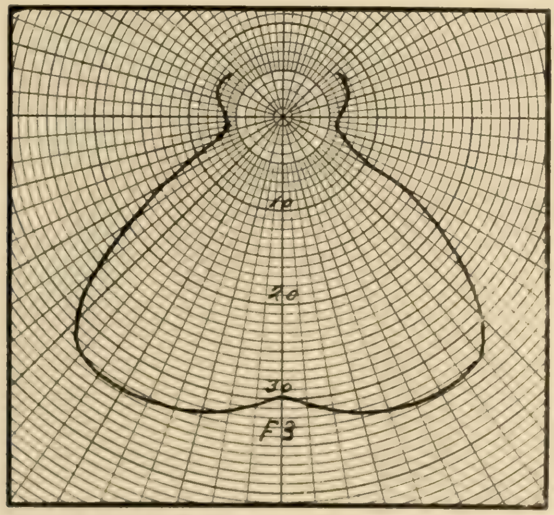


Fig. 3.

forms, viz., carbon, gem, tantalum and tungsten. It has been

customary in the past, and is even more so to-day not to use

Fig. 4.

unshaded electric lamps, but to modify the glare from the filament by some sort of a diffusing medium. In the majority

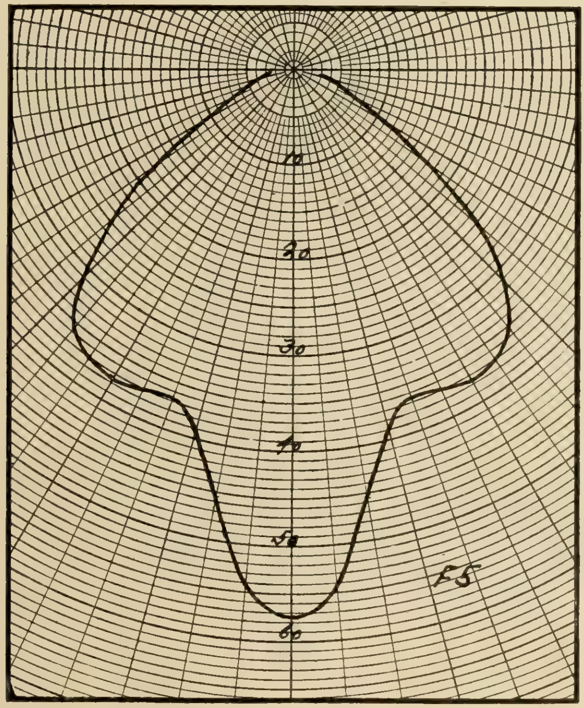


Fig. 5.

of cases such medium, consisting of glass, has been designed

from an ornamental rather than from a useful standpoint. It will be unnecessary in this paper to consider the purely orna

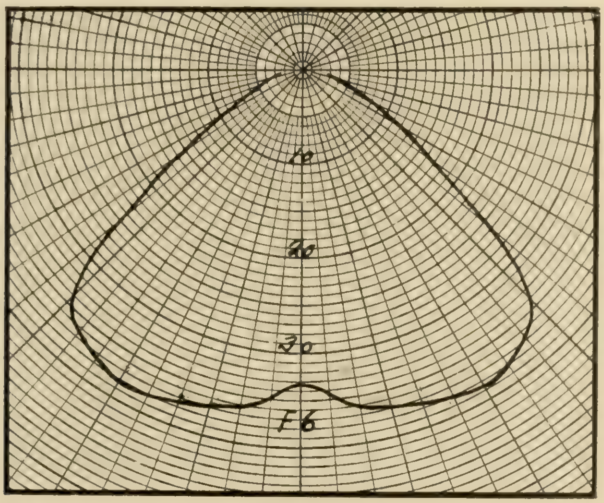


Fig. 6.

mental shade. On the other hand, there are certain utilitarian types of reflectors which are designed to effect the redistribution of light and also to hide the lamp from the eyes, for ex-

Fig. 7.

ample the ordinary tin cone reflector. There are also a large number of reflectors on the market, made both of opal and prismatic glass, which attempt to combine both of these funda-

mental characteristics in lighting glassware. In this paper, I shall endeavor to bring forward some of the limitations which apply in the designing of glassware of these latter types.

Generally speaking, reflectors can be classified into two main

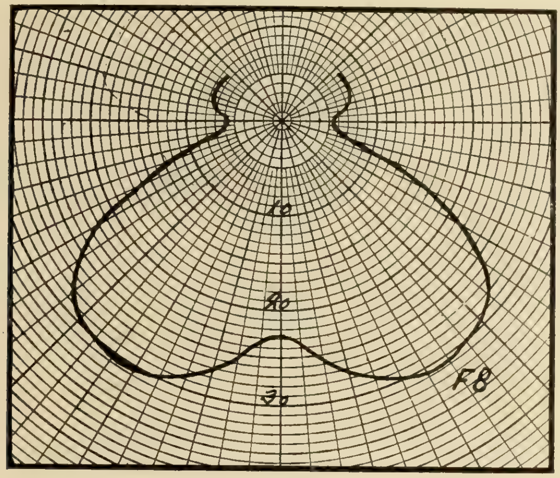


Fig. 8.

divisions, first, those which act primarily by diffuse reflection, and second, those which act primarily by regular reflection.

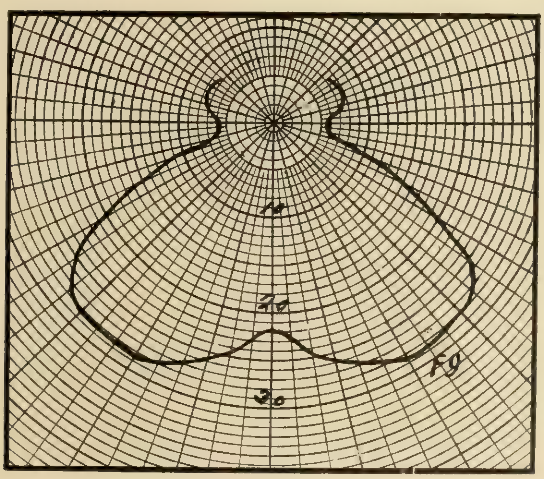


Fig. 9.

There are, of course, some reflectors which act more or less by a combination of these two principles. The first class of reflector is exemplified by the well-known opal reflector in which

a beam striking any given point on the surface is scattered in all directions.

Fig. 1 shows a diagrammatic scheme of irregular or diffuse re-

Fig. 10.

flection. Each ray of light is regularly reflected from the surface on which it strikes, but inasmuch as the surface is broken up into all sorts of irregularities, the different rays of light

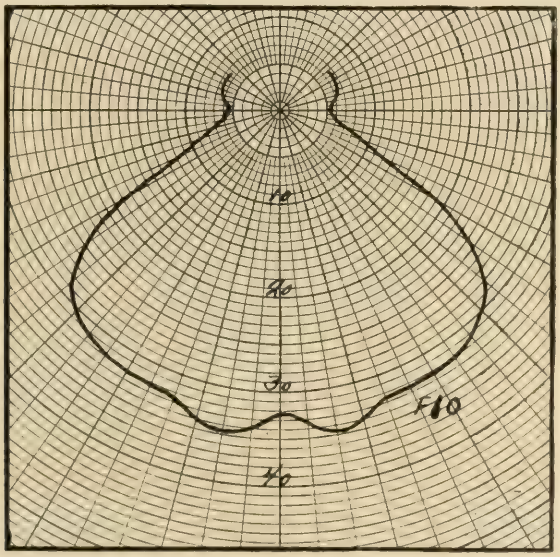


Fig. 11.

are scattered in all directions. Bearing the fact in mind, that when a beam of light strikes a surface giving diffuse reflection and is broken in all directions, it is evident that if the

diffusion is perfect, it makes no difference at what angle the incident beam strikes. Consequently if this be true, in cases

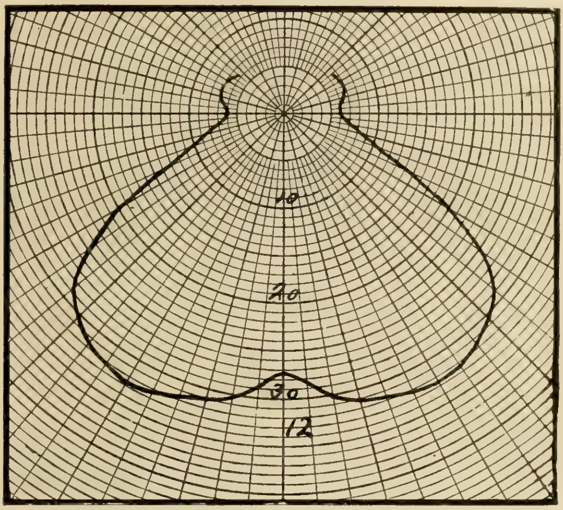


Fig. 12.

of diffuse reflection, the shape of a reflector will not vary the distribution of light. Of course, if the reflector is shaped, for example take the ordinary cone reflector, so as to cut off certain

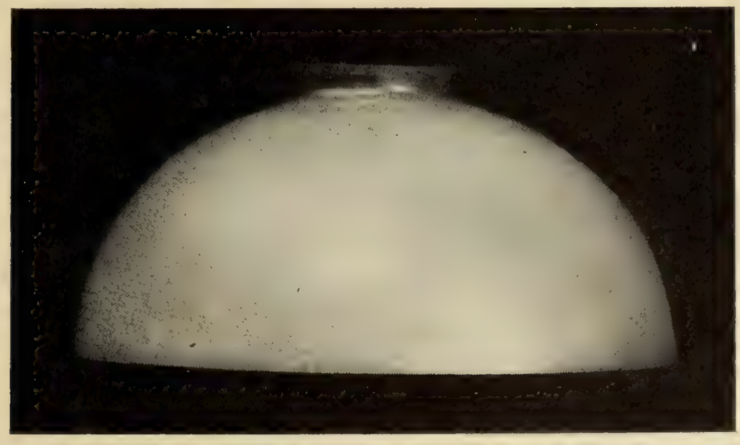


Fig. 13.

of the rays of light, there is a decrease in candle-power in the direction the cut off rays would take, but aside from this, the distribution curves of any form or diffuse reflectors, regardless of the shape, should be practically the same.

This neglects, of course, the question of regular reflection

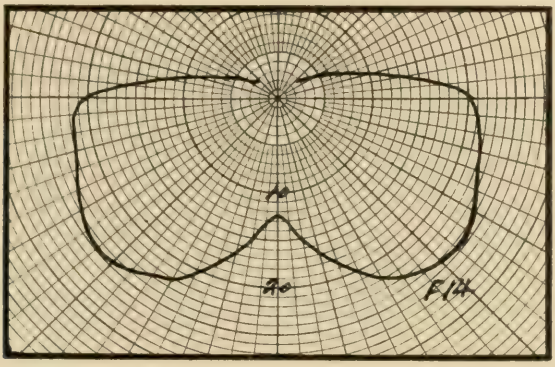


Fig. 14.

from the surface of the reflector, which has to be taken into consideration. Fig. 2 gives the distribution of light about a

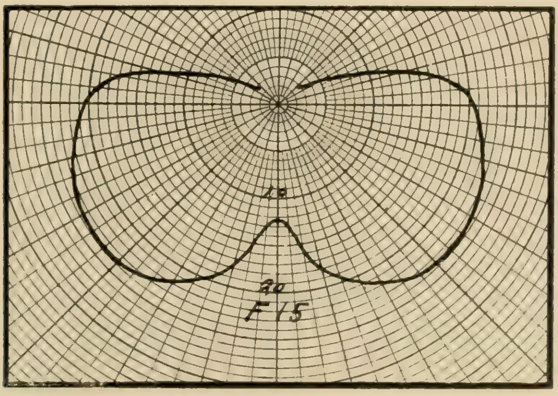


Fig. 15.

25 watt, 20 c.p. tungsten lamp with a plane opal cone 6¾" in diameter, used with a form "O" holder, shown in Fig. 4. The

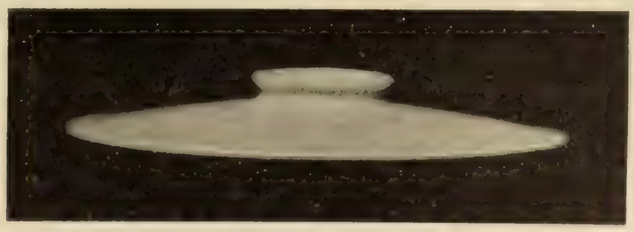


Fig. 16.

strong concentrated light directly beneath the reflector is due

entirely to regular reflection from the surface, glaze or polish, and is not due to the diffuse reflection from the opal. That this is true can be easily seen from Fig. 3 where the same identical reflector has had the surface depolished by acid etching, so

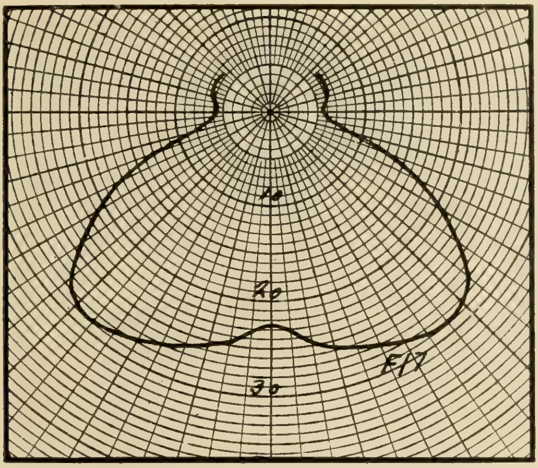


Fig. 17.

that we get purely diffuse reflection. The light which formerly was directed downward has now been thrown a little farther from the vertical, strengthening the light at angles from 15

Fig. 18.

to 45 degrees, so that while the total flux of light in both cases is practically the same, we see that the peak in the distribution

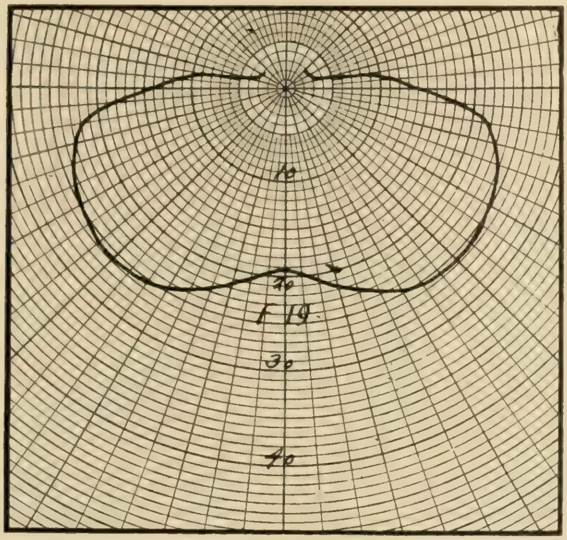


Fig. 19.

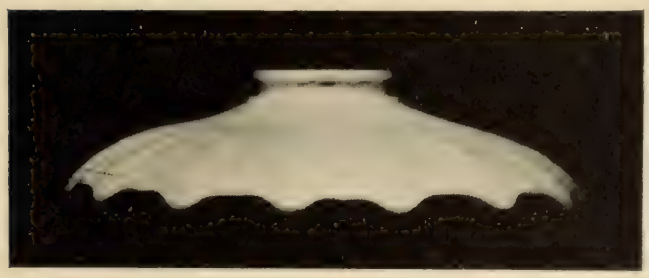


Fig. 20.

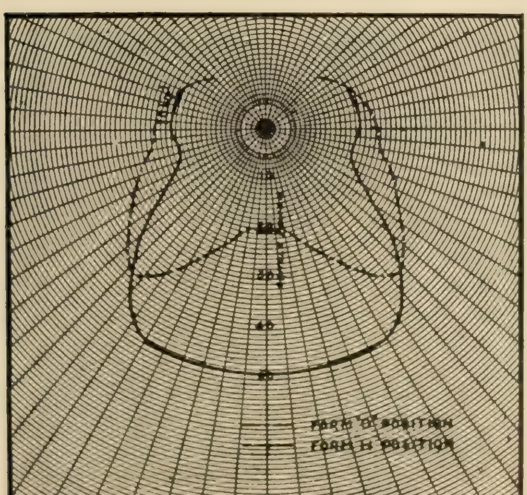


Fig. 21.

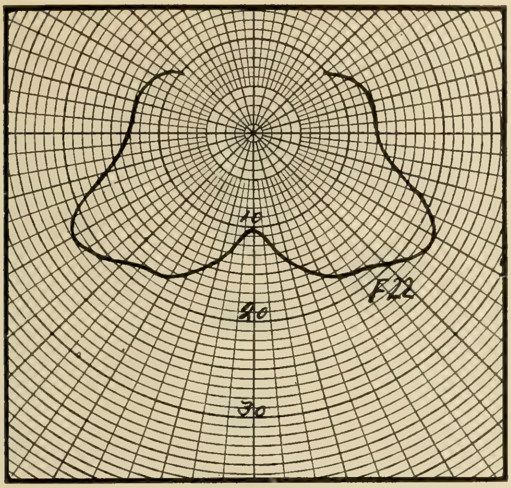


Fig. 22.

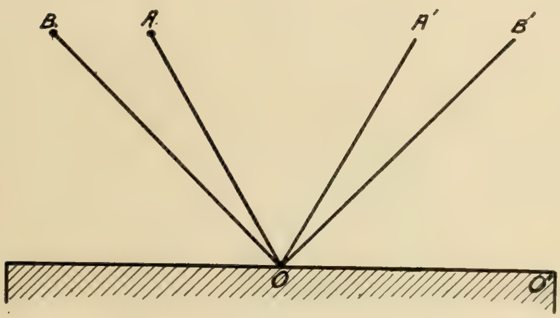


Fig. 23.

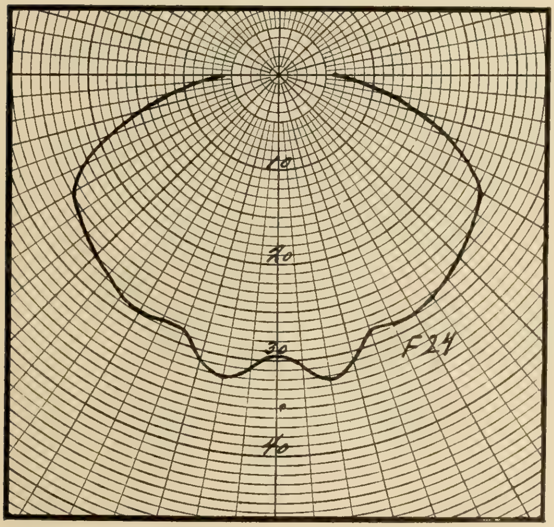


Fig. 24.

of the ordinary plane opal cone is due entirely to surface or regular reflection.

Fig. 25.

Figs. 5 and 6 show the same phenomenon in the case of a

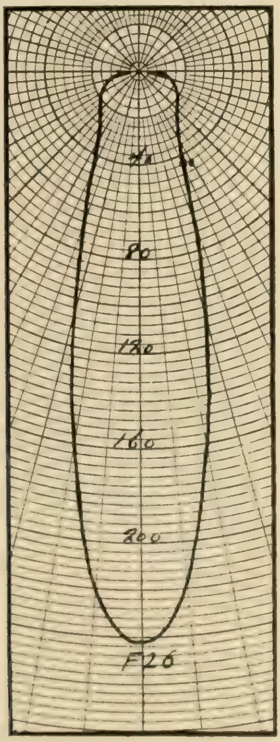


Fig. 26.

green case opal cone 6¾" in diameter, shown in Fig. 7, tested

with a 25 watt, 20 c.p. tungsten lamp, the reflector being used with a form "O" holder. The surface reflection in this case

Fig. 27.

is far more marked than in the former, and it will be noted how this entirely disappears as soon as the surface is depolished.

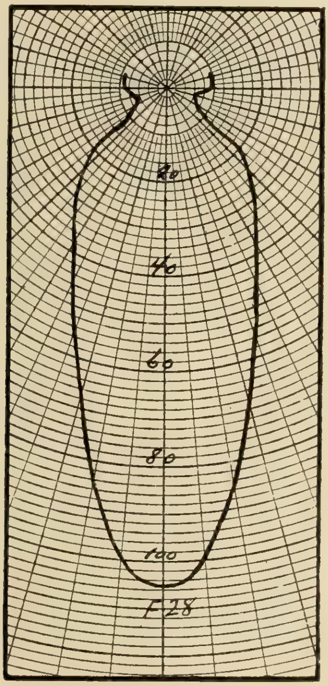


Fig. 28.

Fig. 8 is the curve of a fluted opal cone, shown in Fig. 10, tested with a 25 watt, 20 c.p. tungsten lamp, the reflector being

held in the form "O" position, while Fig. 9 is the curve of the same reflector with the interior surface of the cone depolished.

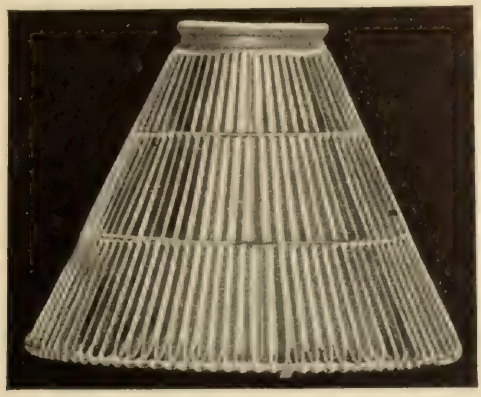


Fig. 29.

It will be noted that in this case, inasmuch as there was no marked regular reflection from the surface of the reflector, that the only marked effect of the depolished surface, is that

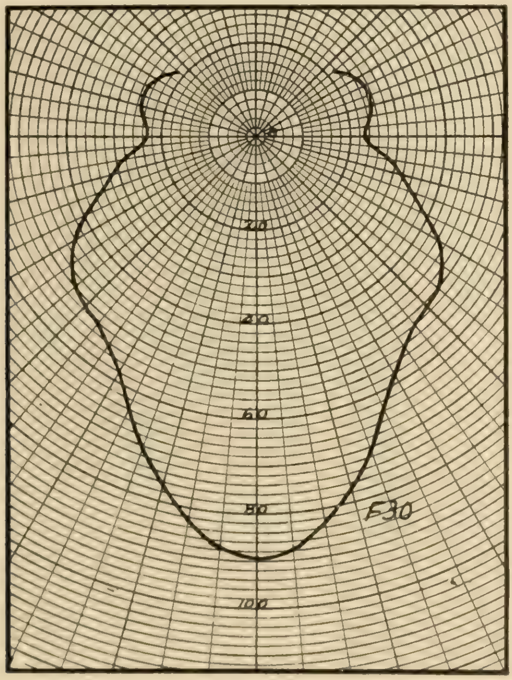


Fig. 30.

it slightly decreases the flux of light in the useful zone. The fluting of the reflector acts also in cutting down the regular

reflection. Fig. 11 represents the curve of the opal dome shown

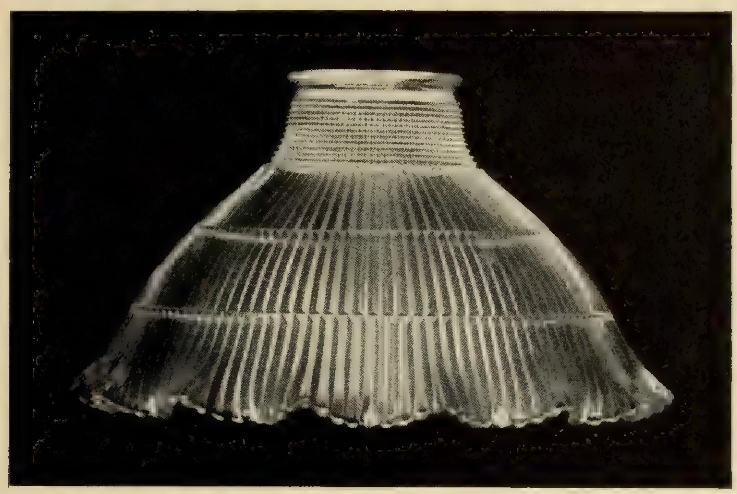


Fig. 31.

in Fig. 13, tested with a 25 watt, 20 c.p. tungsten lamp in the

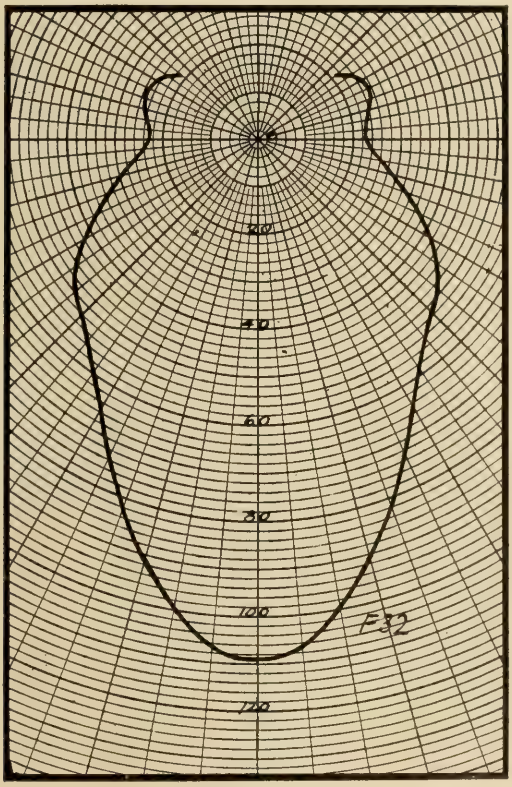


Fig. 32.

form "O" position, and Fig. 12 shows the curve of the same

combination when the reflector has been depolished. Owing to the shape af the reflector, there is very much less surface re-

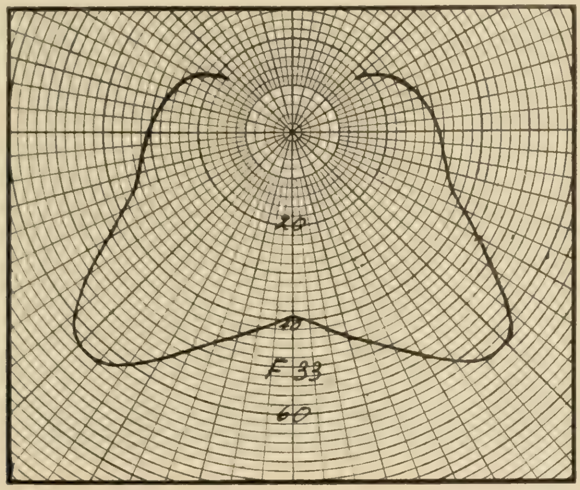


Fig. 33.

flection than in the case of the cone reflector, but whatever

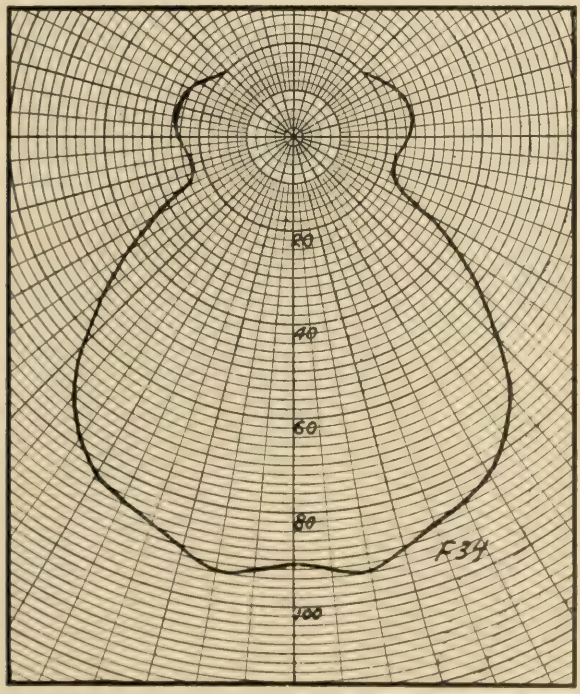


Fig. 34.

effect the surface reflection had, it is practically entirely re-

moved when the interior of the reflector is depolished. Fig. 14 represents the curve of a flat porcelain plate, shown in Fig. 16,

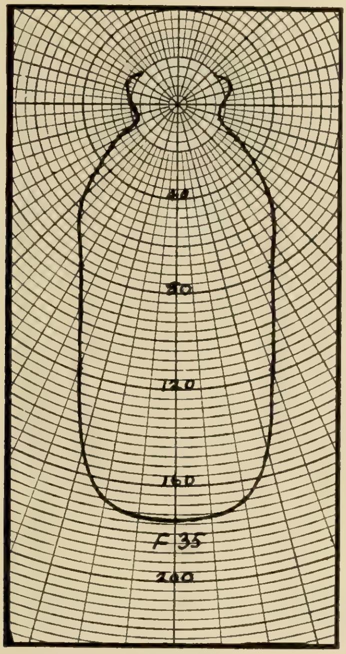


Fig. 35.

tested with a 25 watt, 20 c.p. tungsten lamp in the form "O" position. Fig. 15 represents the curve of the same combina-

Fig. 36.

tion with reflecting surface depolished. It will be noted that the

effect of depolishing the surface of this reflector is to simply permit a little more light to pass above the horizontal, which is to be expected. Fig. 17 shows the photometric curves of a

Fig. 37.

well-known opal bowl reflector 6¼″ in diameter, tested with a 25 watt, 20 c.p. tungsten lamp in the form "O" position. This reflector shown in Fig. 18, has a depolished interior surface.

Fig. 38.

Fig. 19 shows photometric curve of a rather flat opal reflector 8″ in diameter, illustrated in Fig. 20. Tested with the same candle-power lamp, the curve is similar to the one shown in Fig. 17.

There is one thing to be noted in all of these tests, viz.,

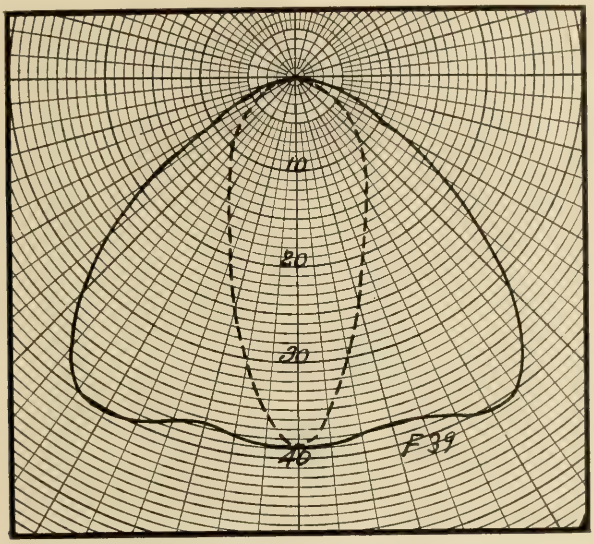


Fig. 39.

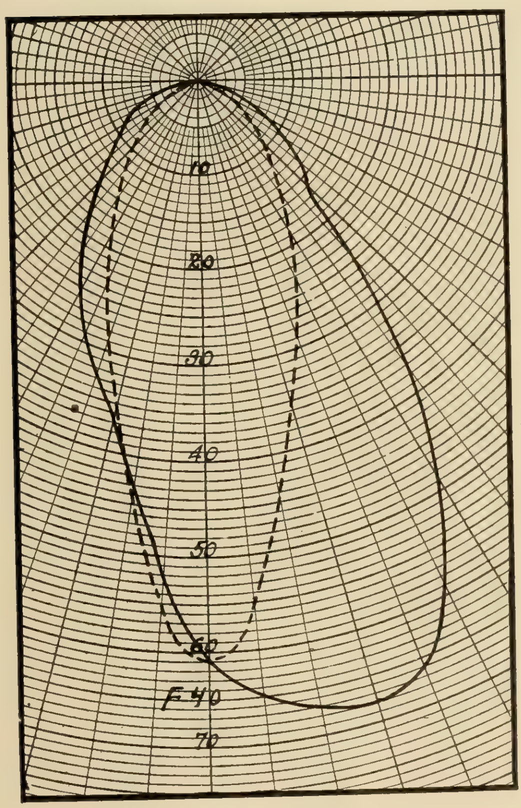


Fig. 40.

that when surface reflection is eliminated by depolishing, we

get purely diffuse reflection, and that the shapes of all the photometric curves are practically the same, with the exception that in the case of those reflectors which do not come far down over the lamp we have, naturally, a stronger lateral distribution. In other words, a study of these curves will show that with opal reflectors having depolished surfaces it is impossible to vary the distribution of the lamp and reflector over a wide range, and that all opal reflectors with a depolished surface will give practically the same distribution of light, irre-

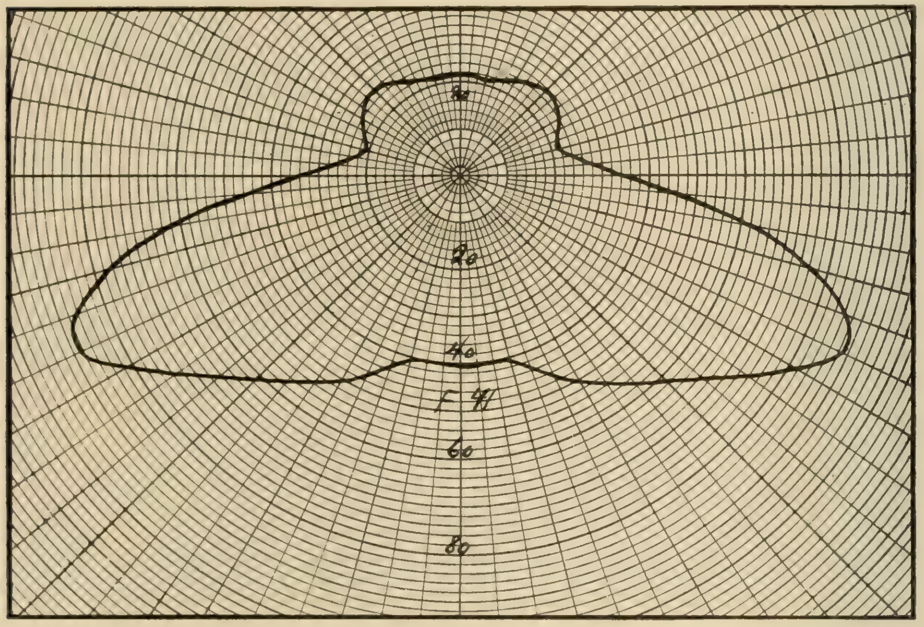


Fig. 41.

spective of their shape. In order to bring this out more clearly, Fig. 21 is shown, in which are placed side by side the curves shown in Figs. 3, 6, 9, 12, 15, 17, 19, and which shows clearly that with the exception of the light which is reflected by the sides of the reflectors, when they are deep, the distribution curves are practically the same, regardless of the shape of the reflector. While opal has been used in the foregoing as typical of diffusing reflectors, there are, of course, other forms of glassware which give this same phenomenon. Fig. 22 shows the curve of a ground glass dome in which there is the same general characteristic distribution, with the exception that more

of the light in this case passes through the dome, and less of it is thrown below the horizontal.

When, however, we come to the question of regular reflection,

Fig. 42.

we will find that it is possible to vary the distribution of light over a wide range. Fig. 23 shows the principles of regular re-

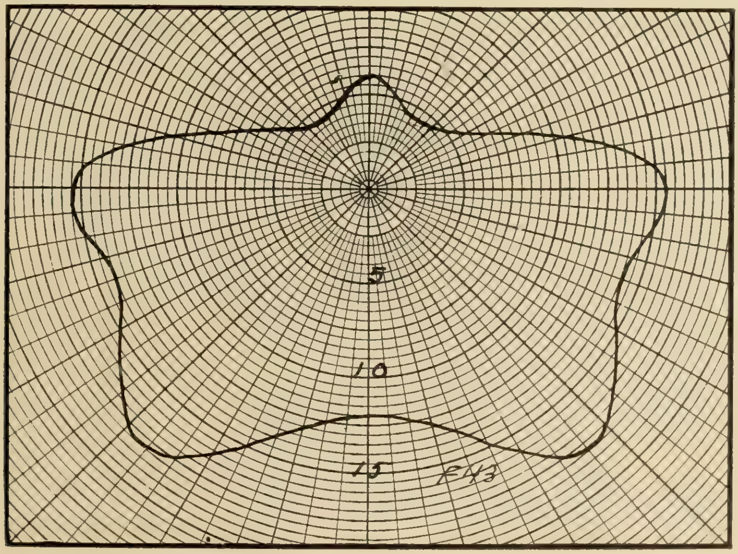


Fig. 43.

flection, in which a ray of light, striking at any given angle, is regularly reflected, that is, the angle of incidence is equal to

the angle of reflection. By properly varying the shape of reflectors in which this principle is employed, it is possible to get a very wide variation in their distribution.

Fig. 44.

Fig. 24 shows the distribution curve of a silvered reflector (illustrated in Fig. 25) tested with a 25 watt, 20 c.p. tungsten

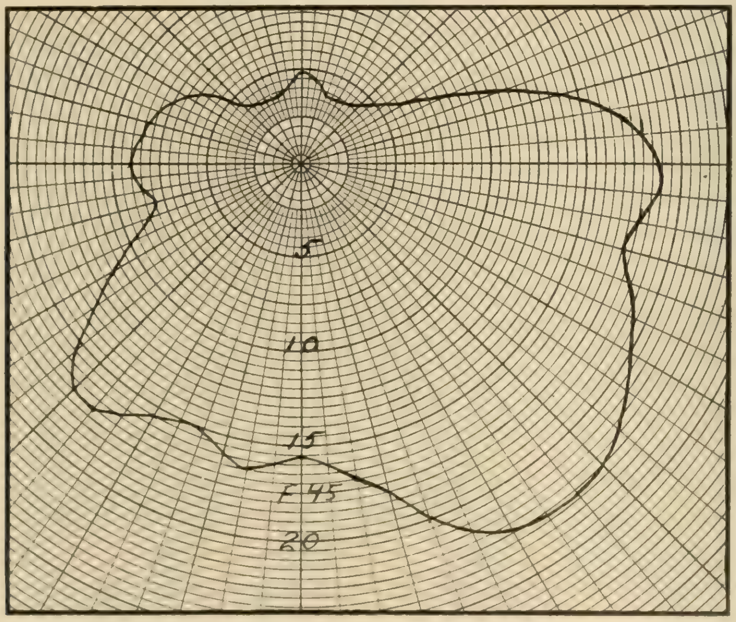


Fig. 45.

lamp in form "O" position. This curve shows a fairly broad distribution of light, and it should be contrasted with the curve

(see Fig. 26) of a plain mirrored cone composed of plain strips of mirror, also tested with a 25 watt, 20 c.p. tungsten lamp in the form "O" position. The mirror reflector is shown in Fig. 27. It will be seen at once by these two curves that there is a marked difference in the distribution of light. The curve of the mirror cone should be compared with the curve of the similarly shaped opal cone, shown in Fig. 3. Fig. 28 shows the distribution curve of a prismatic cone 7″ in diameter and 5″ high, (see Fig. 29) tested with a 25 watt 20 c.p. tungsten lamp in the form "O" position. This curve also should be contrasted with

Fig. 46.

the opal cone curve shown in Fig. 3. It will be readily seen by this that a reflector of this type acts by regular rather than by diffuse reflection. Fig. 30 shows the curve of a concentrating prismatic reflector, having a depolished interior surface (see Fig. 31) tested in form "H" position with a 60 watt tungsten lamp. Despite the fact that there is no surface reflection in this case, it will be seen that the general shape of the curve is concentrated and that the reflector is, as a whole, acting by regular reflection. Fig. 32 shows a similar reflector, similarly tested, in which however, the depolished surface is treated somewhat differently, with the result that while diffusion is obtained by this means, the depolishing does not destroy, to nearly so marked an ex-

tent, the efficiency of the reflector, and the results are nearly as good as obtained with the clear, prismatic type. It is evident from this, that in depolishing the interior surface of a prismatic reflector, utmost care must be used to obtain best results, and that if such care is not exercised, considerable loss may result.

In order to bring out clearly the fact that with a reflector acting by regular reflection, it is possible to get nearly any desired distribution of light, Figs. 33, 34 and 35 show the curves of the well-known Extensive, Intensive and Focusing types of prismatic reflectors, illustrated in Figs. 36, 37 and 38 respectively. Although these reflectors are very similar in their gen-

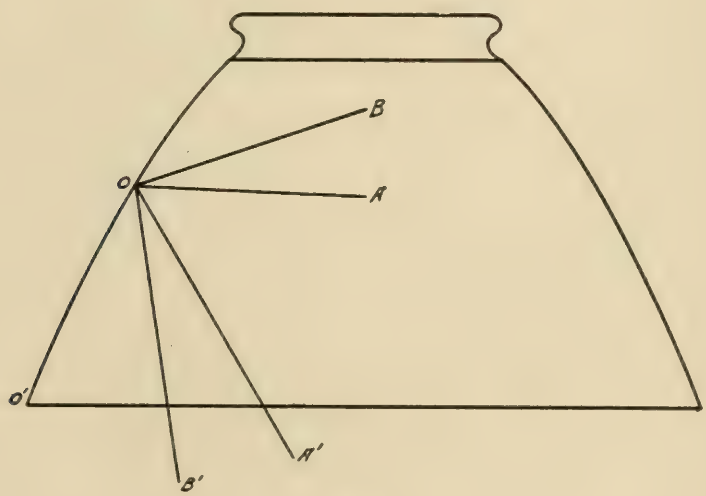


Fig. 47.

eral shape, it will be easily seen that the distribution of light is entirely different in all three cases, and that therefore, when we are dealing with regular reflection, obtained by means of prismatic or mirrored surfaces, we can vary the distribution of light to suit the needs of the case.

I have not attempted, in this paper, to bring out anything except the fact that with diffuse reflection, the possibilities of redirection of light are limited, whereas with regular reflection, the possibilities are very much greater. As an example of this latter, there are shown in Figs. 39 and 40 the distribution curves obtained with a concentrating prismatic reflector and a flat plate. On the interior of the plate are certain redirecting prisms. The full line in Fig. 39 shows the curve in one plane, and the dotted

line the distribution in the plane at right angles to the other. The full and dotted lines in Fig. 40 show similar results. The unit in Fig. 39 is used primarily in car-lighting, being placed in the center of the deck, where it is desirable to throw the light up and down the aisle rather than sidewise, whereas the unit shown in Fig. 40 is used over dining car tables, where it is desirable to throw the light not against the wall, but on the table at an angle of about 15 degrees from the vertical.

Fig. 41 is another example of the possibilities in redirecting light. It is the horizontal distribution of the diffusing prismatic reflector shown in Fig. 2 and used primarily for street lighting. It will be seen that in this case the maximum light is thrown diagonally over the street at an angle of 25 degrees from the curb line, and that only 50 per cent. of the maximum is thrown directly across the street and less than 25 per cent. directed toward the nearby sidewalk.

Fig. 43 shows the distribution of light about a prismatic globe by which the majority of the light rays are thrown below the horizontal. The globe itself is shown in Fig. 44.

Fig. 45 shows the distribution from a similar globe, illustrated in Fig. 46, identical in shape, but in which there are totally reflecting prisms on the back and diffusing and redirecting prisms on the front. The distribution curve of this should be compared with distribution curve Fig. 43. This comparison shows the marked variation possible in two globes, identical in shape, but in which the prisms are of different design.

From a brief consideration of the laws of regular reflection, it will at once be seen that the position of the source of light with reference to the reflecting surface, will make a great difference in the light reflected. Thus, if a source of light be in the position A (Fig. 47) the reflected ray will take the direction OA′, whereas if the source of light be moved to B parallel to surface OC′, the reflected ray will be OB′, or a different direction from the other. It is therefore evident that in the case where a source of light and reflector are taken together in order to get predetermined results the position of the source of light with reference to the reflector must be fixed, and that if the relative position of the source of light to the reflector is changed,

the resulting distribution of light will also be changed. This is clearly brought out in Fig. 48 in which are shown distribution curves of the same reflector and lamp, the full line representing the photometric results when the reflector was in the relative position to the lamp for which it was designed, and the dotted line representing the results obtained when the position of the reflector was moved ⅞″ higher. It is thus seen in dealing with regular reflection, that it is absolutely essential to have the source of light and the reflector in relatively correct positions in order to get the results desired.

From a study of the curves in this paper, it is evident that further developments in the control of light by any means known at the present time are to be expected from the use of those mediums which give regular rather than diffuse reflection.

DECEMBER MEETING.

"THE LIGHTING OF RAILWAY CARS.

BY MR. GEORGE E. HULSE.

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I will treat this subject under two heads: First, methods of obtaining light; Second, its application to secure proper illumination.

Methods of Lighting:—The methods and materials used for car lighting have been in general those used for other forms of lighting, but special methods of application have always been necessary in order to make these general methods applicable to the conditions met with in railroad service. If a method of lighting is used successfully for general lighting, it does not follow that it can be applied successfully to car lighting, and methods especially successful when applied to cars do not find the same application in general use. An example to this is the use of compressed oil gas. Oil gas was manufactured and used for house lighting before it was applied to car lighting, but while it has been practically abandoned for general use, eighty per cent. of all passenger cars in service are lighted with it at the present time.

I will not go into a description of the multitudinous forms of lighting which have been applied to cars. The candle, of course, was used in its day, and the mineral oil lamps did good service in their time. Acetylene, at the time of the discovery of calcium carbide, was hailed as an ideal car illuminant, but its development has not shown that it is the equal of oil gas in efficiency or economy, especially since the development of the incandescent mantle for oil gas lighting. This, combined with the fact that acetylene came into the field after oil gas had become firmly established with years of satisfactory service, has made the application of acetylene extremely limited.

Many other forms of lighting have been used to a limited extent, and abandoned as unsatisfactory.

At the present time there are two systems which are in use and which will probably continue to be applied in the future.

They are, compressed oil gas, known in this country as "Pintsch" gas, and electric lighting. For the future, gas lighting will probably do the larger part of the work, while electric lighting will be applied to certain classes of equipment where its use is especially desirable and where considerations of cost and operating difficulties do not enter.

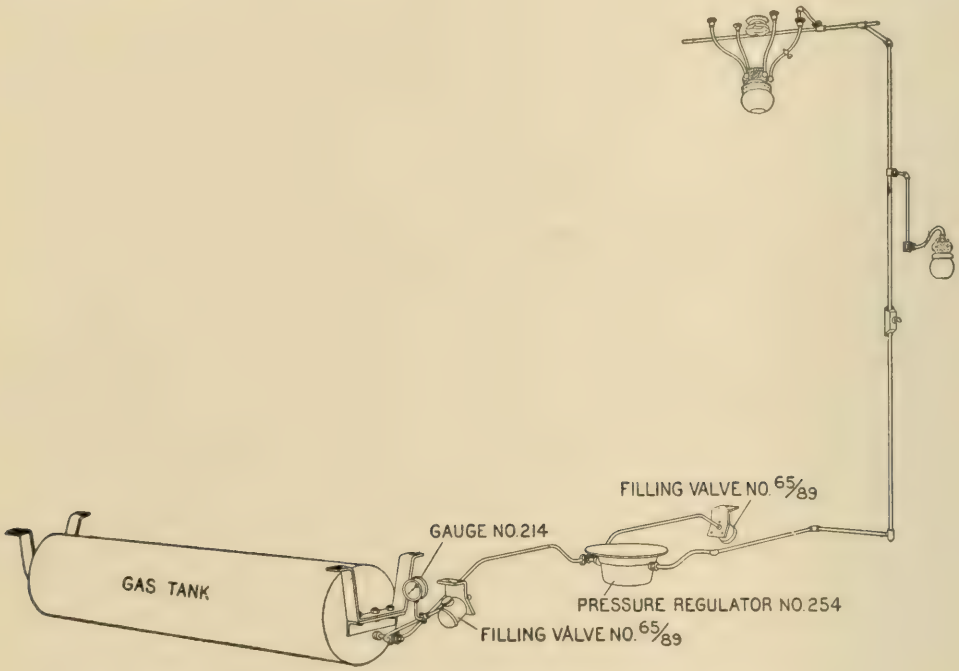

Fig. 1.—Diagram of Pintsch gas equipment using mantle lamps.

The Pintsch System:—The poor service given by oil lighting led to experiments toward the adoption of gas to car lighting. As the storage space available was limited, it was necessary to carry the gas under pressure in order to have a sufficient supply on the car, and also to have a gas of comparatively high illuminating value. Coal gas, of low candle-power primarily, lost at least fifty per cent. of its illuminating value when compressed to a point high enough to give sufficient storage. Oil gas has not only a much higher candle-power uncompressed, but when compressed to ten atmospheres, loses only ten per cent. of its illuminating power. Several systems of oil gas lighting were introduced in the late seventies, but that in use throughout most of the world at the present time was brought out in Germany by Julius Pintsch.

Pintsch gas is made by the distillation, or "cracking" of petroleum oil in cast iron or clay retorts, or in steel generators filled with fire-brick checker-work. A fixed gas is formed which has for its principal ingredients, methane and heavy illuminants with a very small amount of hydrogen. It has a heating value when compressed of 1,250 B. t. u's. per cu. ft. After passing through proper washing and purifying apparatus, the gas is compressed to 12 atmospheres in store-holders from which it is carried to the railroad yards by suitable pipe lines. The car holders are filled from these pipe lines. The car equipment (see Fig. 1) consists of one or more welded steel holders to contain the gas supply, two filling valves, a pressure gauge, a regulator for reducing the holder pressure to that at which the lamps operate, the pipe line for carrying the gas from the holders to the lamps, and the lamps or burners. All fittings for both the low and high pressure piping are especially designed for the work. The pressure regulator is placed under the car near the holders so that the amount of high pressure piping is small and none of it is inside the car.

The pressure regulator reduces to the proper pressure and maintains this pressure constant with varying amounts of gas used.

Before the development of the incandescent mantle for car lighting the gas was burned in regenerative lamps fitted with from two to four burners of the union jet type. The design of the burner cluster and reflectors was such that the lamps gave an excellent candle-power distribution. The hemispherical candle-power was about 35, with a gas consumption of 3.25 cu. ft. per hour.

After the incandescent mantle came into general use for house lighting, it was tried for car lighting, but it was found that the upright mantle would not stand the vibration and shocks received in railroad service.

One of the earliest, and probably the earliest completely successful application of the inverted mantle was to car lighting. This was due to the fact that while the development of the inverted mantle for general use had to contend with low and

varying gas pressure, in car lighting a sufficient and uniform pressure is at all times available.

The first mantles used were of small size, giving about 28 c.p. with a gas consumption of 0.8 cu. ft. per hour and were arranged singly or in clusters of four. Later a mantle was developed which gave 90 candle-power with a gas consumption of 2 cu. ft. per hour. The use of this mantle has made feasible the remodeling of the flat flame lamps to mantle lamps, and these lamps are being rapidly made over. The substitution of one of these mantles for a four flame lamp means an increase in the gas storage capacity of the already installed equipment of sixty per cent. Since 1905 when the mantle lamp was introduced in America, over 4,000 cars have been equipped and lamps for 2,650 cars have been remodeled; a total of 33,481 new lamps and 17,300 remodeled lamps form and composition, to withstand the rigors of railway service. They give very satisfactory results as to durability. A careful test, made on cars of a railroad running into New York, where a record of the life of each mantle was kept, showed, in a year's test, an average life of 110 days for each mantle.

The simplicity of construction of the lamp used is shown in Fig. 2. Gas enters the lamp from the roof line through the shut off cock and gas arm to the body casting No. 3140. Into this body casting is fitted the gas orifice No. 3046 with screen No. 2748. The flow of gas from this orifice draws air through the horizontal channels in the casting No. 3052 forming a mixture which burns at the plural jet burner No. 3049, bringing the mantle No. 3044 to a high state of incandescence. It will be noticed that no gauzes or other means are used to prevent striking back. These are not necessary as the velocity of the flow of gas from the orifice is greater than the velocity at which the ignition can travel back to the orifice.

The mantle lamp is in very extensive use in Europe, in England, France, and especially in Germany where the entire passenger car equipment of the Prussian State Railway is fitted with it.

There are upwards of eighty-five gas plants for the manu-

facture of Pintsch gas in the United States and Canada, owned in some instances wholly or in part by the railroads, but most of them by the Pintsch Compressing Company. Gas is delivered to the car holders and charged for at a uniform rate, the amount of gas supplied being measured by the increase of gauge pressure.

The holders are made of exact size and the contents of a holder can always be determined by multiplying its capacity by

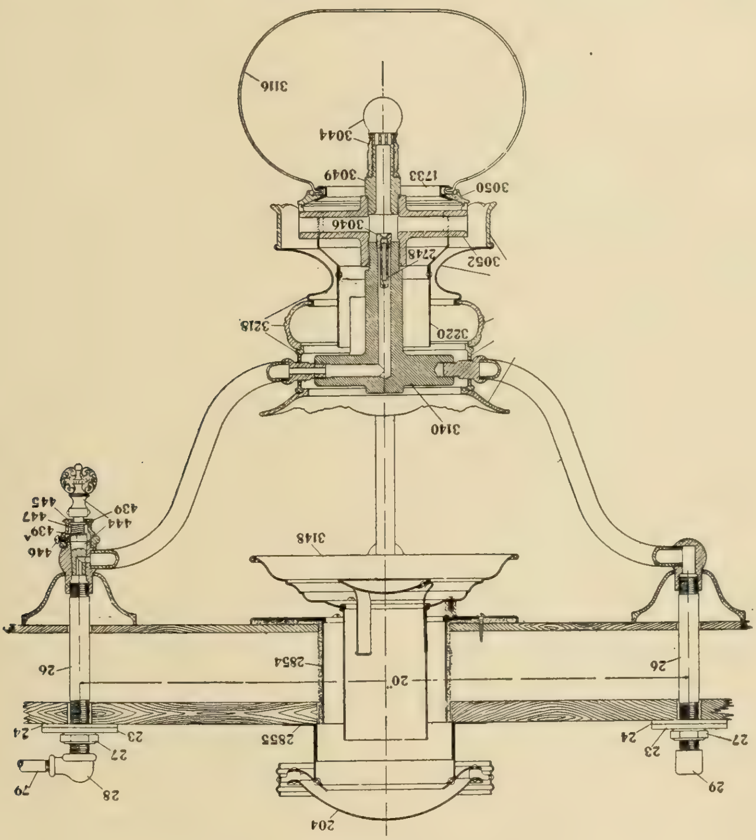

Fig. 2.—Section of mantle lamp.

the gauge pressure in atmospheres. This feature, besides furnishing a means of measuring the amount of gas supplied, is important for determining the hours of lighting which a holder contains and also for the purpose of car interchange.

Cars using Pintsch gas are dependent on stationary plants, but this has not been found to be a disadvantage, principally because the time required to charge a car is so short. It can be done, if necessary, at a division station stop.

Cars in branch line service which do not reach central stations are supplied by transport service without trouble or expense

to the railroad company. This transport service has been carried on heretofore by using a large steel holder on a freight car. These holders are filled to fourteen atmospheres, and in order to make all the gas available for filling car holders to ten atmospheres, a compressor is necessary.

We are now developing a high pressure transport system in which the gas is compressed to 100 atmospheres in steel bottles. We have found that each bottle filled with gas at 100 atmospheres contains 133 times its volume of free gas. By using this method the use of a compressor is avoided, 90 per cent. of the gas in the bottles is available for filling car holders to 10 atmospheres, and the total weight required for transporting the gas is reduced 50 per cent. and the space required 95 per cent.

There is more or less of a popular prejudice against the use of gas for car lighting owing to the alleged danger from it in case of wrecks. This danger does not exist, as the behavior of Pintsch gas in wrecks in the past has shown.

The gas itself is non-explosive, and the range of explosive mixtures of gas and air are extremely low—from 4 to 10 per cent. Its ignition temperature is high, and it is difficult to light when escaping under pressure.

The quantity of gas carried on a car is so limited, and in case of rupture of a tank or pipe connection its diffusion is so rapid that a combustible mixture is not made. There are four times as many cars equipped with Pintsch gas as the entire rolling stock of the United States, and this system would not have been in extensive use if its employment involved a hazard to life or property.

ELECTRIC LIGHTING.

Electric lighting on steam railway cars is accomplished by either of three methods, known as:

1. The "Head End System."
2. Straight Storage.
3. Axle Lighting.

The Head End System comprises a generator driven by a steam engine either in the baggage car at the head of the train or on

the locomotive. From the generator the current is carried back to the cars by means of appropriate train lines. To maintain the lights when the locomotive is detached from the train it is necessary to use a storage battery on one or more of the cars.

The system most used in this country is that having a steam engine, either reciprocating or turbine in the baggage car, steam for its operation being brought from the locomotive by suitable hose connections. A few equipments are being used with the generator on the locomotive. This latter arrangement entails a heavier first cost for equipment, as several locomotives may be used in the hauling of one train over its trip.

The head end system gives good results as to efficiency and economy, but its great disadvantage is that the lighting can only be used when a car is in a train with a generator equipment. If cars are equipped with batteries to supply light during such time as the locomotive is disconnected, the proper arrangements for charging the batteries entail a sacrifice of simplicity and economy.

In the *Straight Storage System* each car is equipped with a set of storage batteries of sufficient capacity to supply current for the lamps for the desired trip. As ordinarily applied the equipment is simple, consisting of the lamps, storage batteries and charging receptacles. At the terminal yards the batteries are charged by current obtained from a stationary power plant. The lamps burn directly from the batteries, no voltage regulator being used.

This method of lighting would be ideal if the electric storage battery could be perfected. However, this system cannot come into general use with the present battery on account of the fact that the charging of the batteries consumes too much time.

Car lighting systems dependent upon stationary plants are feasible as shown by the Pintsch system, but the time required for charging must not interfere with car service. Another feature which is not always taken into consideration with this system is the variation in voltage at the lamps, especially when the batteries are worked near their full capacity.

Axle Lighting.—This term has come into general use to designate a system by which power is taken from the car axle to run a generator to supply current for the lamps in the

car. The equipment consists of a generator mounted on the car body or truck with some form of drive between the car axle and the generator, a regulator to give the proper output of the generator at varying speeds, a storage battery to maintain the lights when the speed of the generator falls below that at which it gives the proper voltage, an automatic switch to prevent the

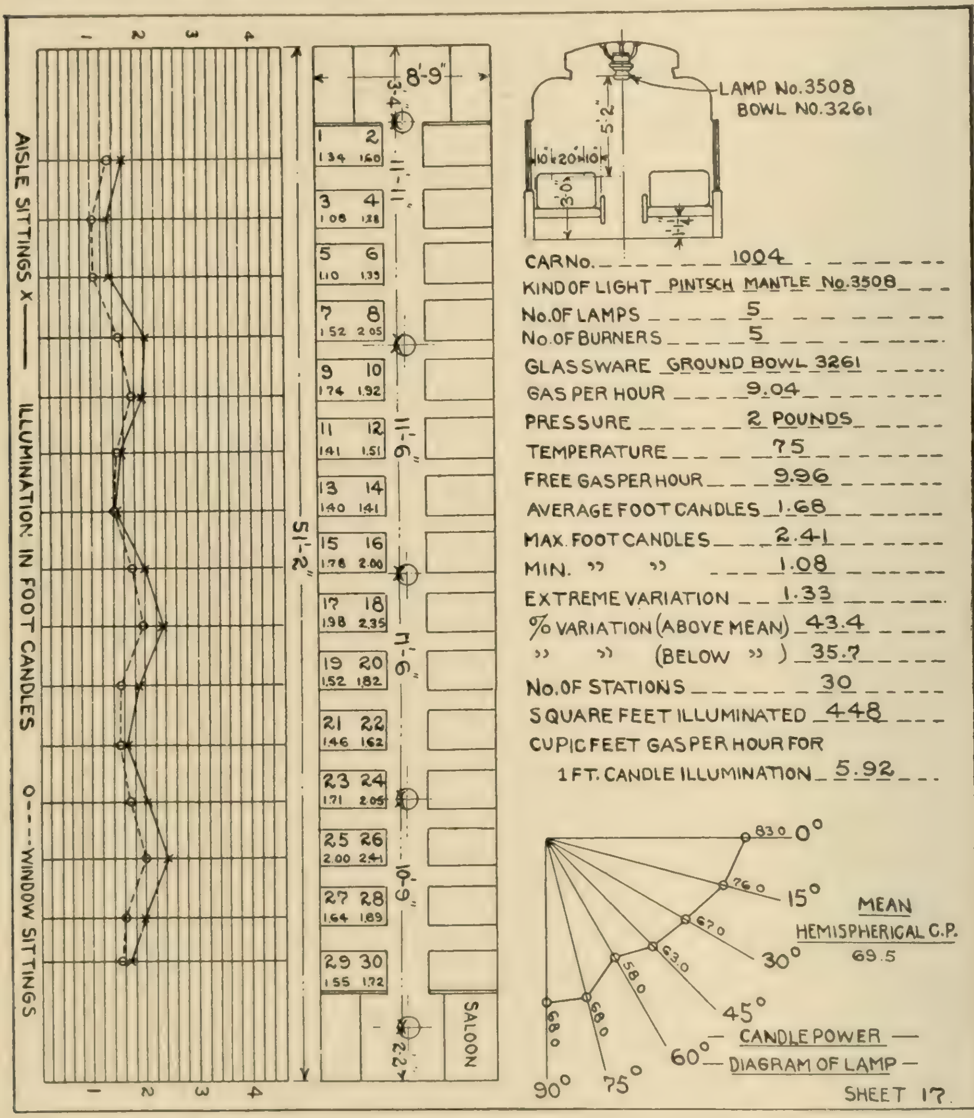

Fig. 3.—Illumination of coach by gas center lamps.

discharge of the batteries through the generator, a lamp regulator to keep the lamp voltage constant, and means for keeping the polarity of the battery charging current constant.

This system renders each car absolutely independent of a

stationary plant, and in spite of its seeming complexity, is the only one of the three systems which is capable of general application to cars. The problem of working out a satisfactory system of this kind is not simple, but it is now being done with success, and axle lighting will probably be the most generally

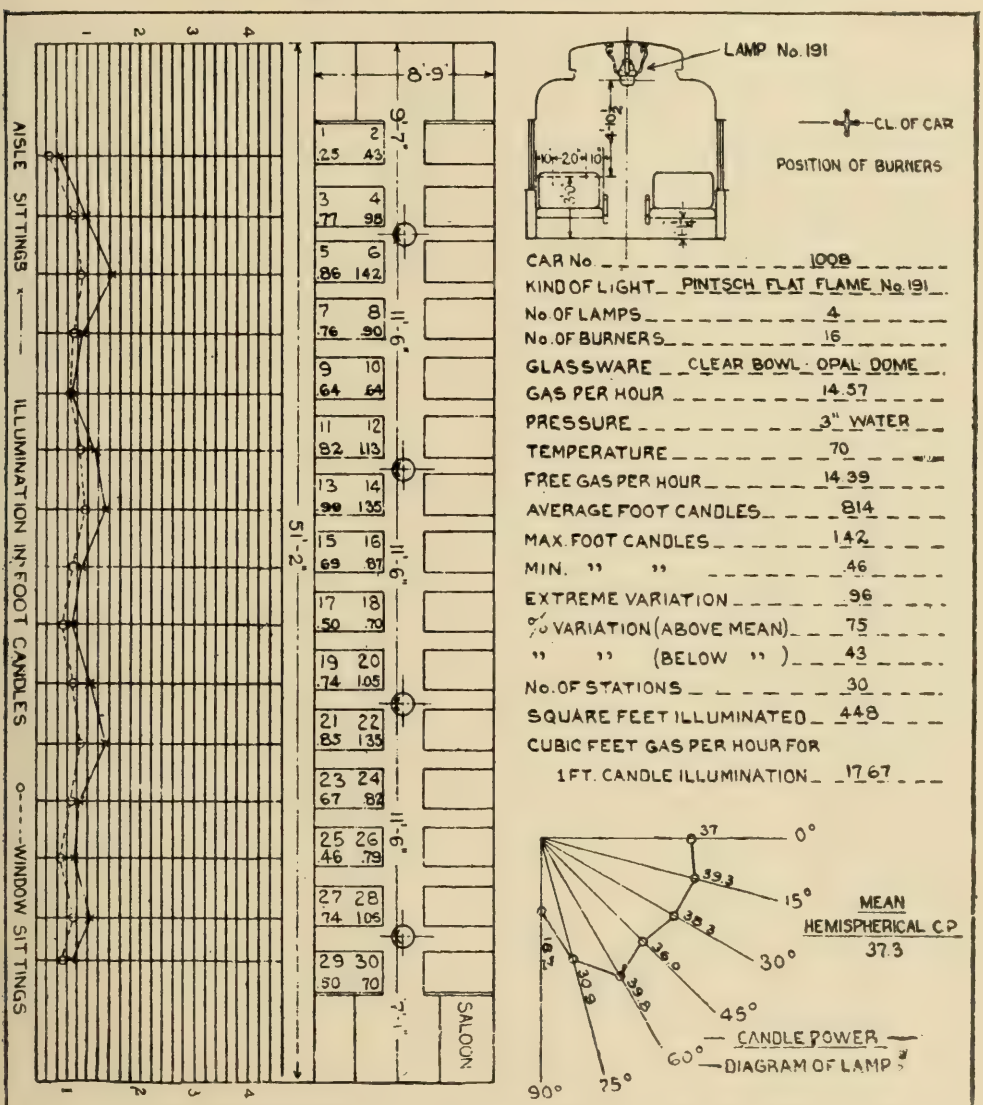

Fig. 4.—Illumination of coach by gas center lamps.

used form of electric light for steam railroads. A properly designed axle system is superior to head-end or straight storage, as it renders the car available for use in any territory and does not necessitate lay-overs at charging plants. The axle system properly worked out, gives the best treatment of the storage battery,

and the success of electric car lighting in its present state of development depends upon the efficiency of the storage battery

CAR ILLUMINATION.

The problem of obtaining an adequate and proper illumination of passenger cars is not an easy one to solve, as many

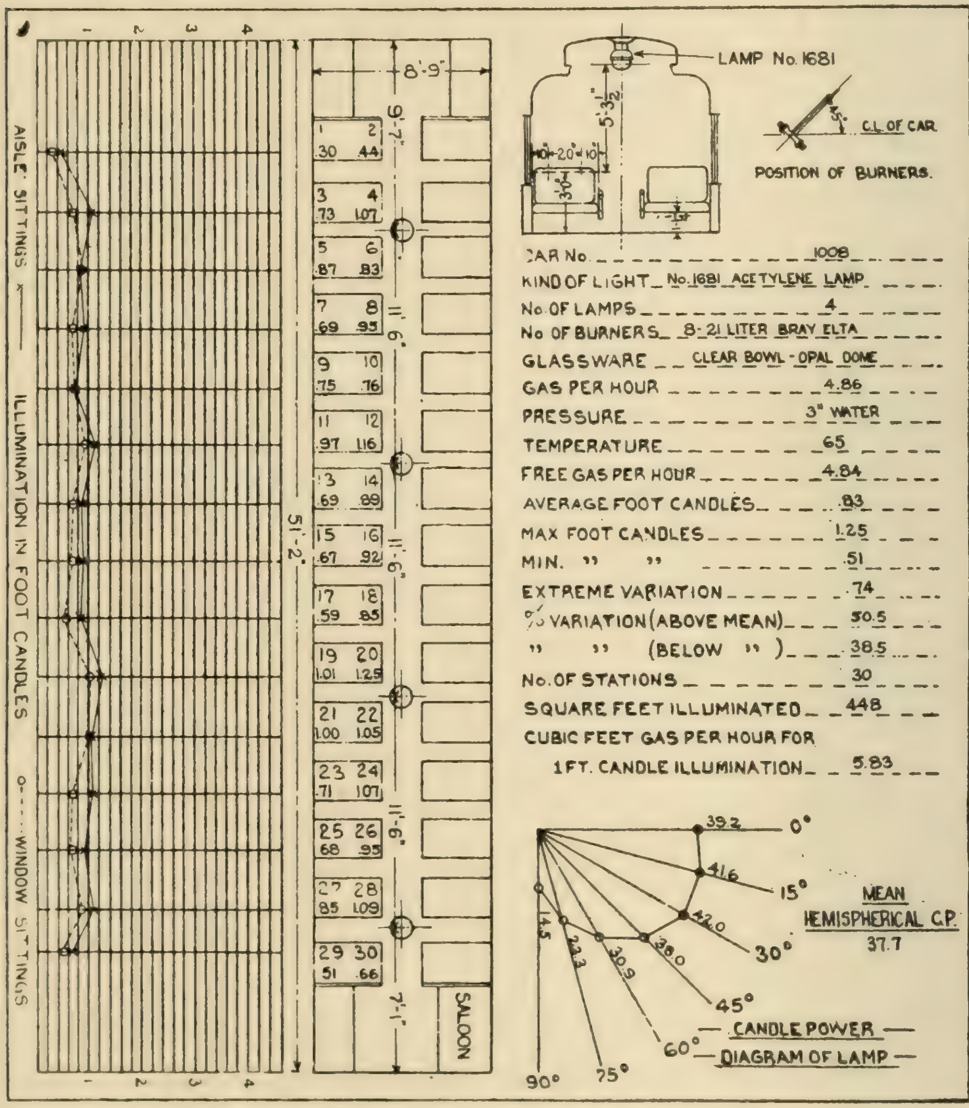

Fig. 5.—Illumination of coach by gas center lamps.

special conditions are met with. The construction of a car is such that it is difficult to place the light sources out of the range of vision. This feature did not count for so much when gas lamps with flat flames were used, as the specific intensity of the gas flame was so low that its effect on the eye was

not bad, but since the incandescent mantle has come into use with its high intensity, it is absolutely necessary to use a diffusing glass. With the Pintsch mantle, an enclosing globe of sufficient size and diffusing power has been used, so that the intensity on the surface of the bowl is not over two candle-power

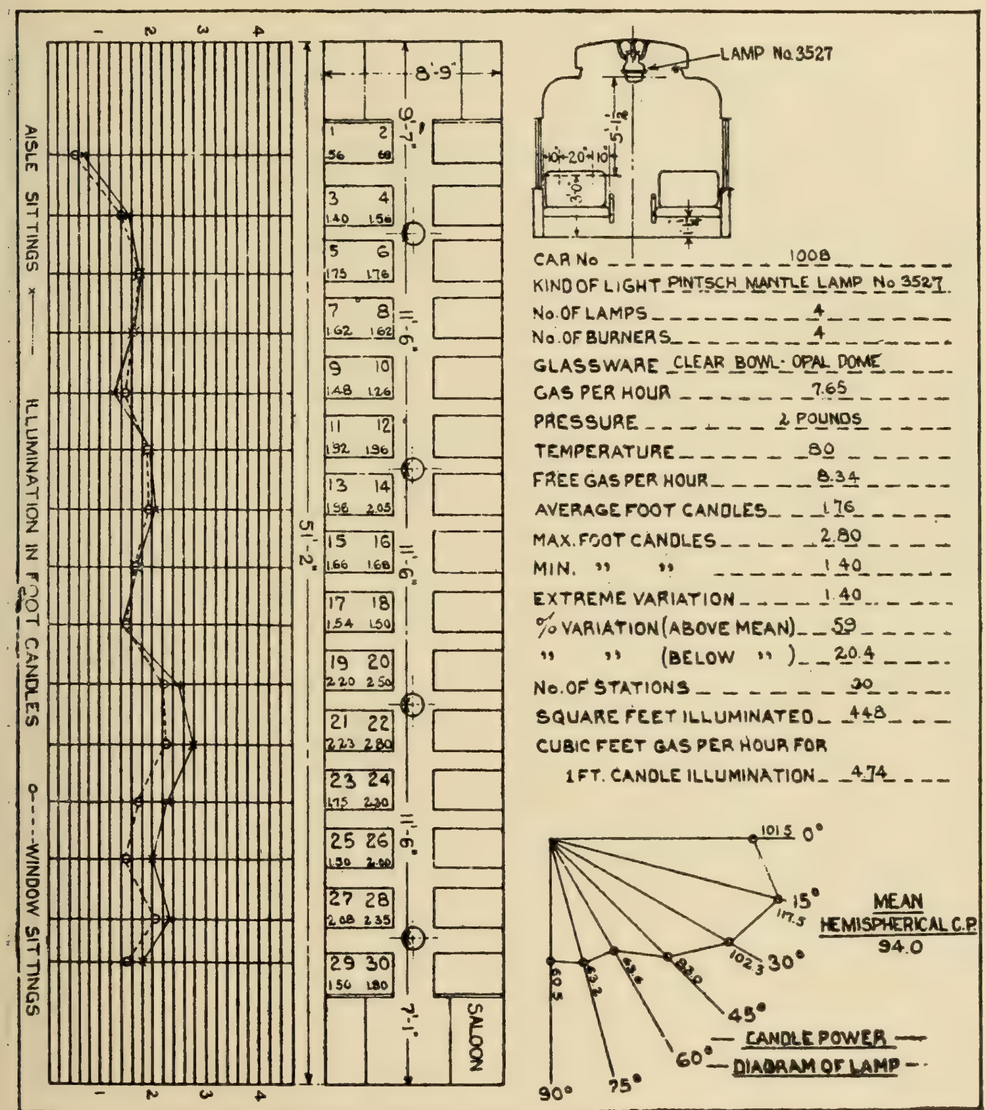

Fig. 6.—Illumination of coach by gas center lamps.

per square inch. Installations of electric lighting have been the worst offenders in regard to exposed light sources, as in many cases clear bulbs have been used without shades or diffusing globes. The use of a large number of such lamps in a car with highly polished trimmings has made a glare which quickly

fatigues the eyes. Conditions, however, are much improved in later installations and good illumination rather than quantity of light is being sought for.

In nearly every type of passenger car, the chief use of the artificial illumination is for reading. The lighting should be so

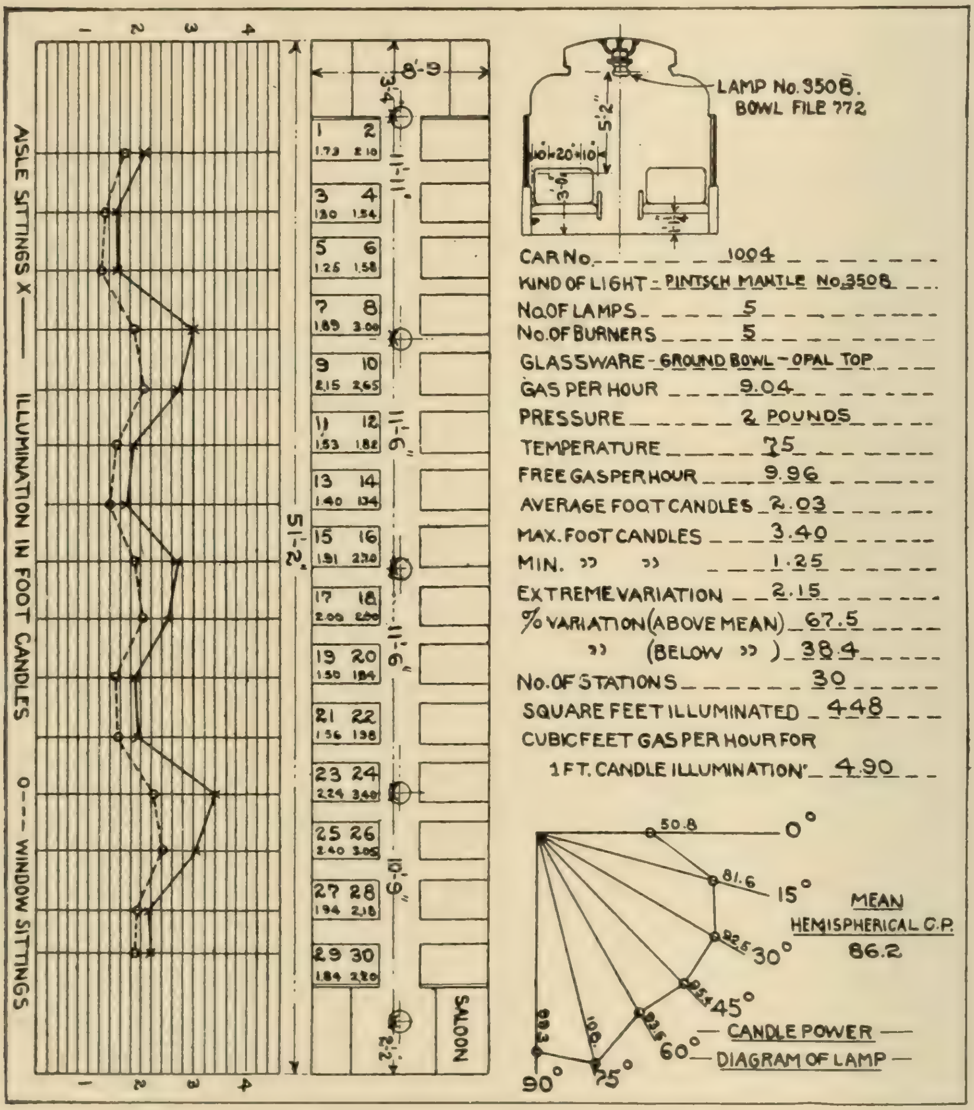

Fig. 7.—Illumination of coach by gas center lamps.

designed that a good illumination falls on the book or paper of the passenger, while there are rest spaces to which the eye can be directed without the light source coming in the line of vision. This rest space should have a fair amount of general illumination. In the ordinary passenger coach it has been found

that these results are best obtained by the use of ceiling lamps suspended from the top deck of the car, with a spacing of from six to ten feet. With the proper candle-power distribution of the light source, uniform illumination can be produced.

The accompanying diagrams, made from the results of illu-

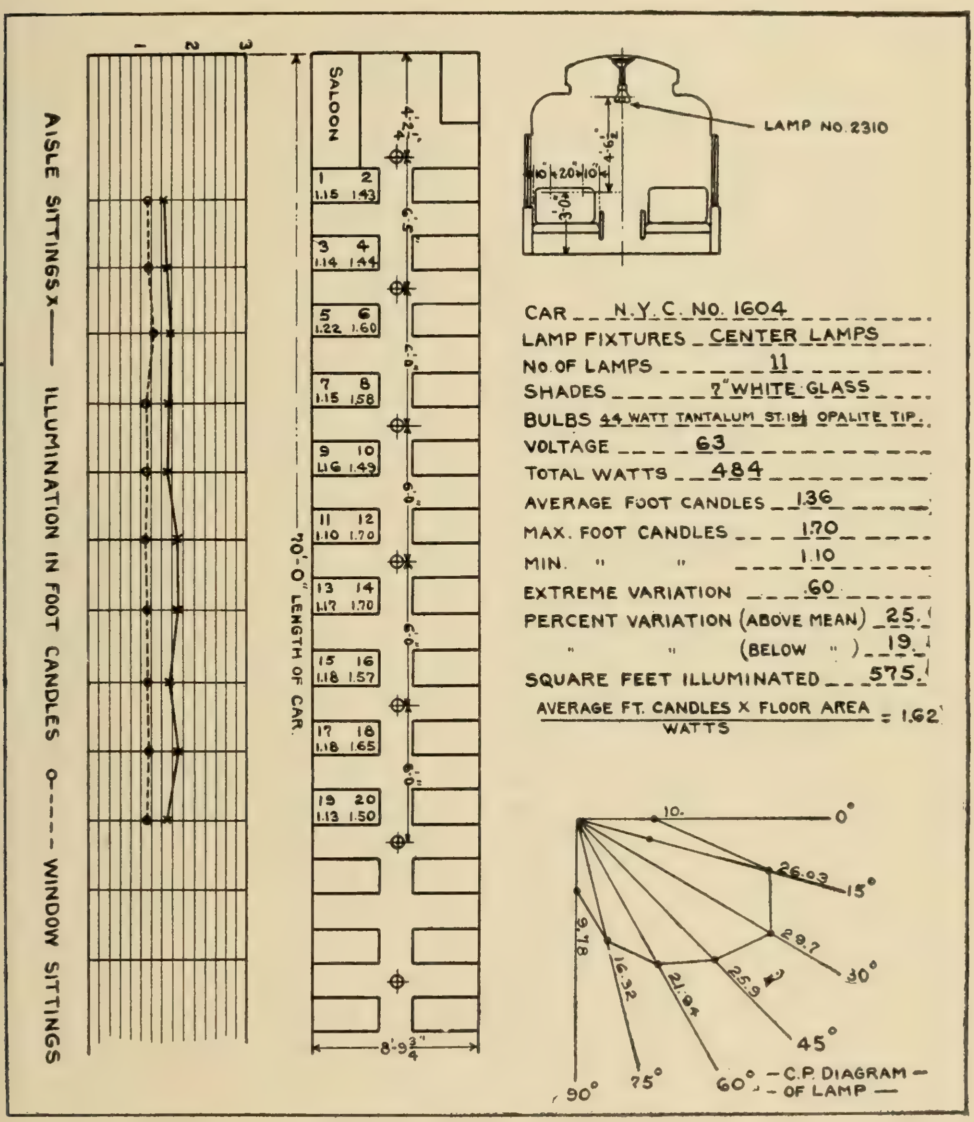

Fig. 8.—Illumination of coach by electric center lamps.

mination tests on cars in service, show the results obtained by this method. In these tests the illumination was measured on a plane corresponding to a passenger's paper, at the proper height. During the measurement a medium-sized passenger occu-

pied the sitting, so that the results obtained take the head shadows into account:

Figs. 3, 4, 5, 6 and 7 show results of such tests in coaches lighted with various forms of gas center lamps. These are tests from cars as actually found, and while the lamp arrange-

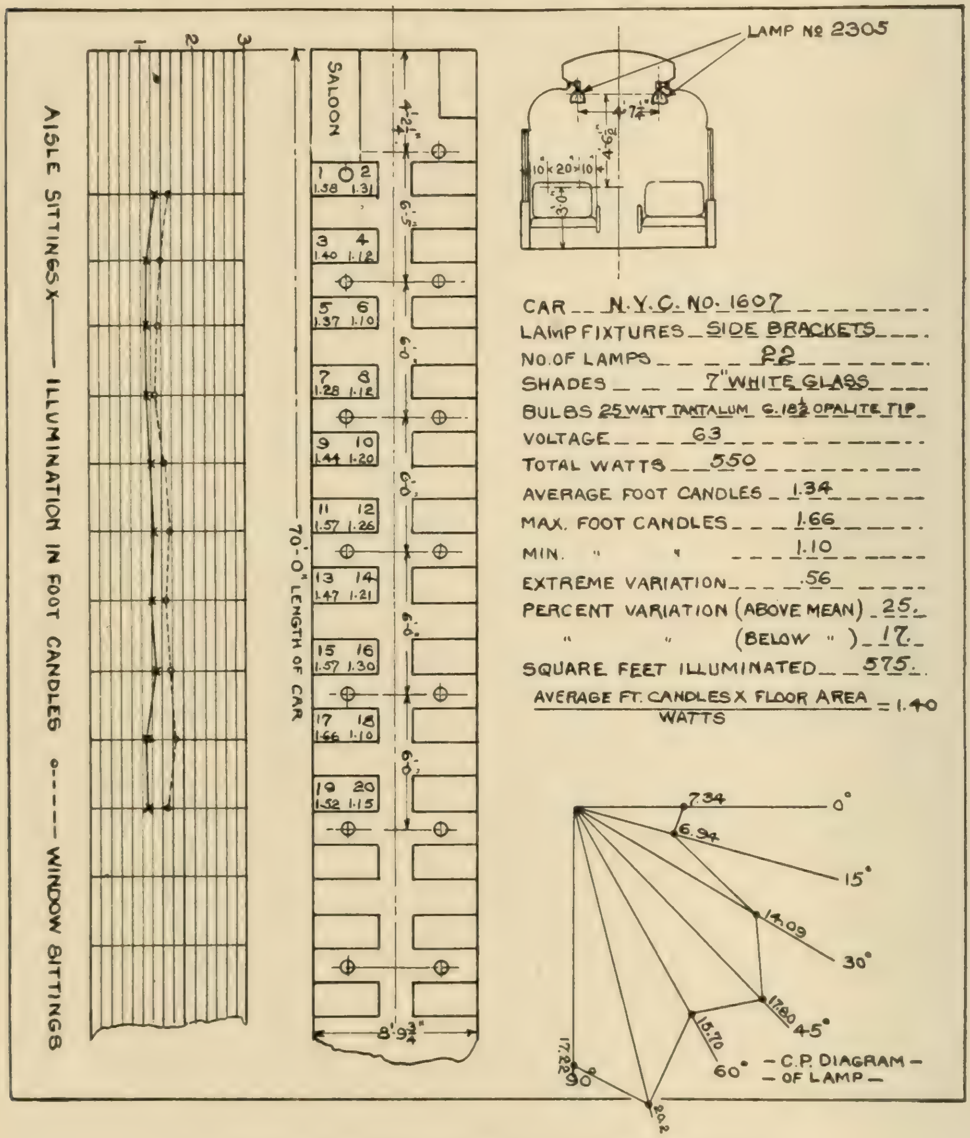

Fig. 9.—Illumination of coach by electric side lights.

ment is not ideal, it will be noted that satisfactory results are obtained as to quantity of light and uniformity of distribution, especially with the mantle lamp.

Another method of lighting used to a large extent for electric lighting of coaches is the use of brackets or pendants on the

lower deck sill, the idea being that a more uniform distribution can be obtained in this way. A short time ago the opportunity afforded itself to test two cars of exactly the same size and construction, one fitted with center lamps and the other with side brackets, shades of the same quality of glass but suitable

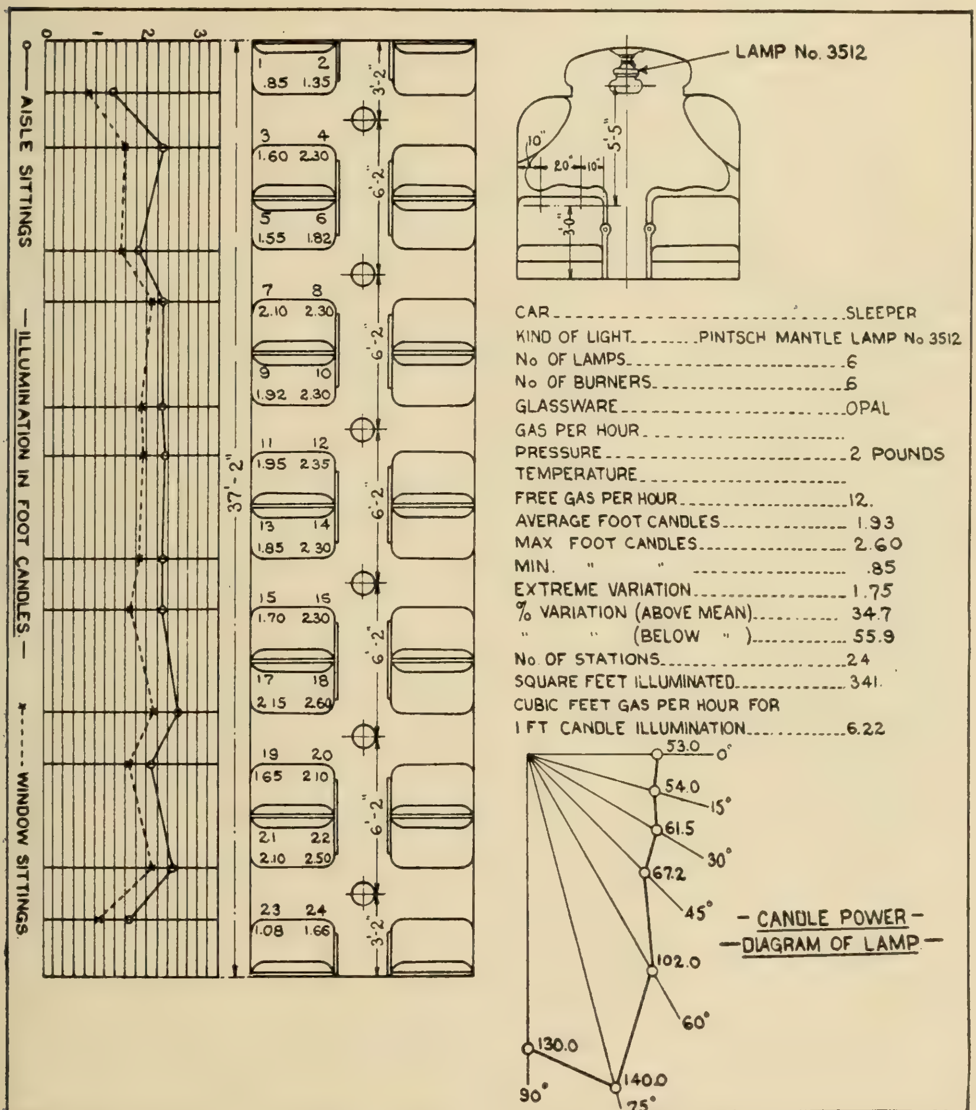

Fig. 10.—Illumination of sleeper by mantle lamps.

shape for best results, being used in both cars. The results, as will be noted by referring to the diagrams (Figs. 8 and 9), show that as far as uniformity of illumination goes, there is nothing to choose between the two, although the center fixtures give the most efficient results as to the total watts used. Side light-

ing is objectionable because it is impossible to get the lamps out of the range of vision, as they are directly in front of the passenger, and there are always numerous shadows on the paper from the multiplication of light sources. The interior of the car also has a better appearance with a few well designed center lamps than with a number of side fixtures.

A very efficient way to light a coach would be to have the lamps provided with reflectors to throw the light not only down, but also toward the front of the car in a manner similar to that

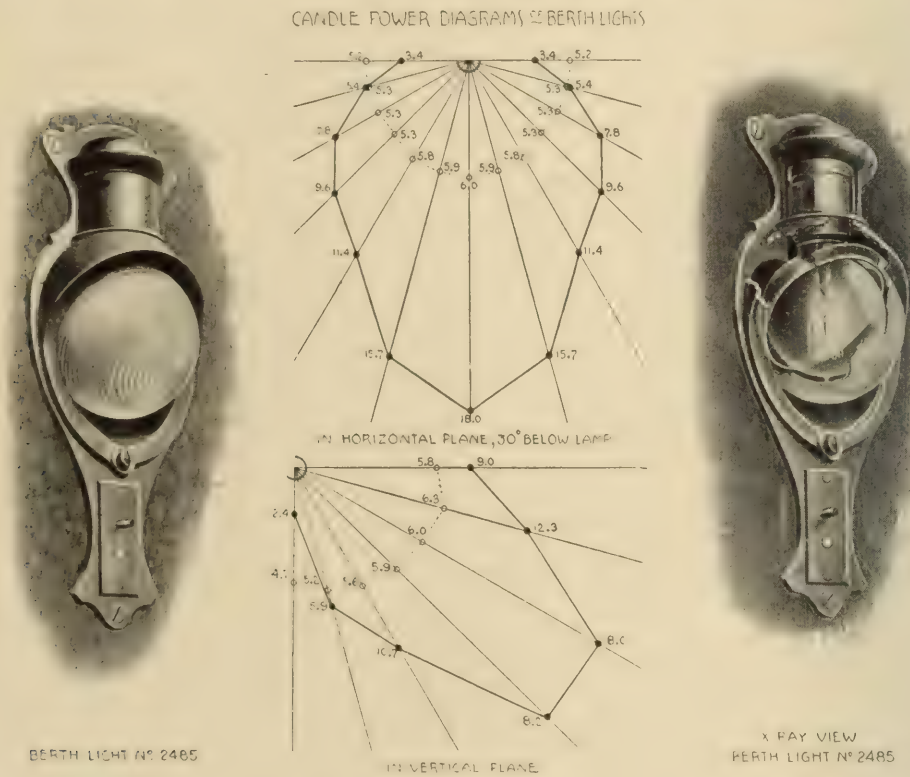

Fig. 11.—Electric berth lamp.

used in some cases for public hall lighting. This would increase the light on the passengers' papers and remove all the glare from the eye. There is yet to be found the railroad company which would consider a lighting scheme which required that the reflectors on the lamps be reversed every time the direction of the car was changed. The problem is, however, being worked out along lines which we believe will insure its practical operation.

Fig. 10 shows the illumination diagram of a sleeping car equipped with mantle center lamps. The lighting is ample and

uniform and as the lamps are well up to the ceiling and opal diffusing glassware used, the eye is not subjected to any glare from exposed light sources.

Sleeping cars, in addition to center lamps, are provided with berth or reading lamps in many cases. These are used when the

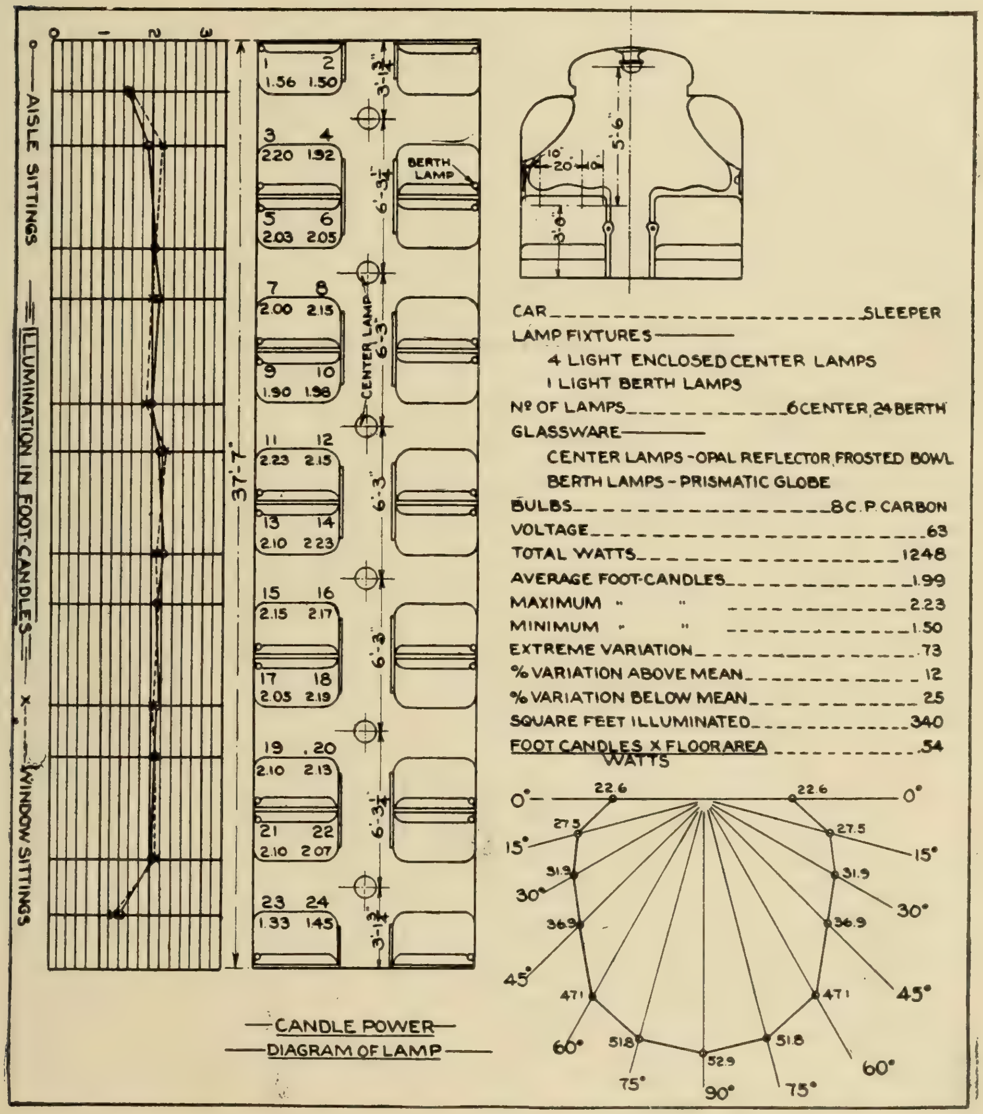

Fig. 12.—Illumination of sleeper by electric lamps.

berth is made up, for light for undressing and at other times for reading lamps.

Most sleeping cars are equipped with a berth lamp consisting of a miniature bulb which, when not in use, is concealed in the paneling at the side of the car. Pressing a spring brings out the

bulb and turns on the current. A new type of berth light has recently been brought out which permits of the use of a standard size Tungsten bulb and is operated by a small push button

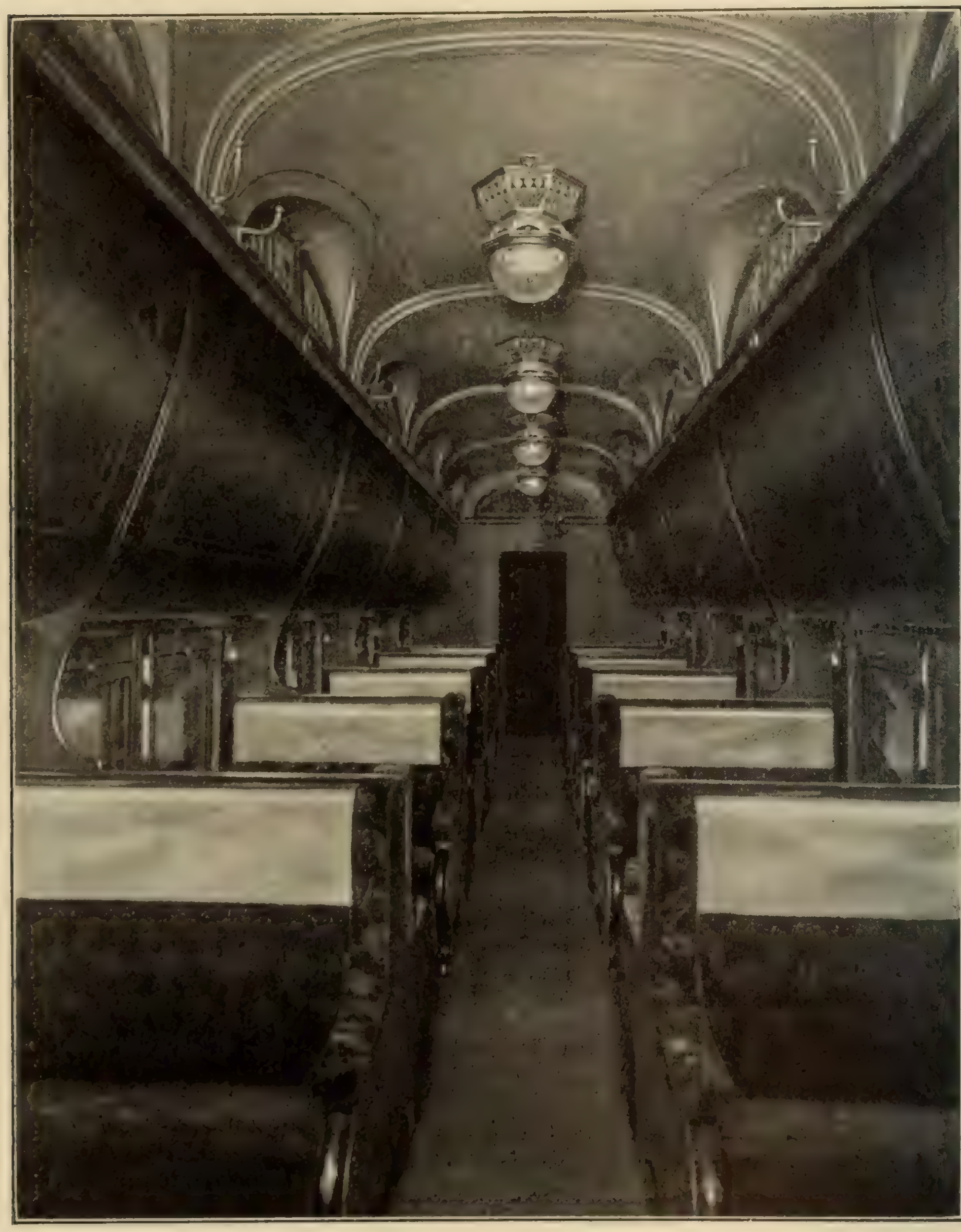

Fig. 13.—Interior view of sleeping car.

switch. A prismatic enclosing glass is used to give the candle-power distribution, which gives the maximum intensity on the

passenger's book and the minimum in the eye of the passenger in the opposite seat.

Fig. 11 shows an exterior and interior view of this lamp and also the candle-power diagrams. In these diagrams the full line shows the candle-power of the new type of fixture using a

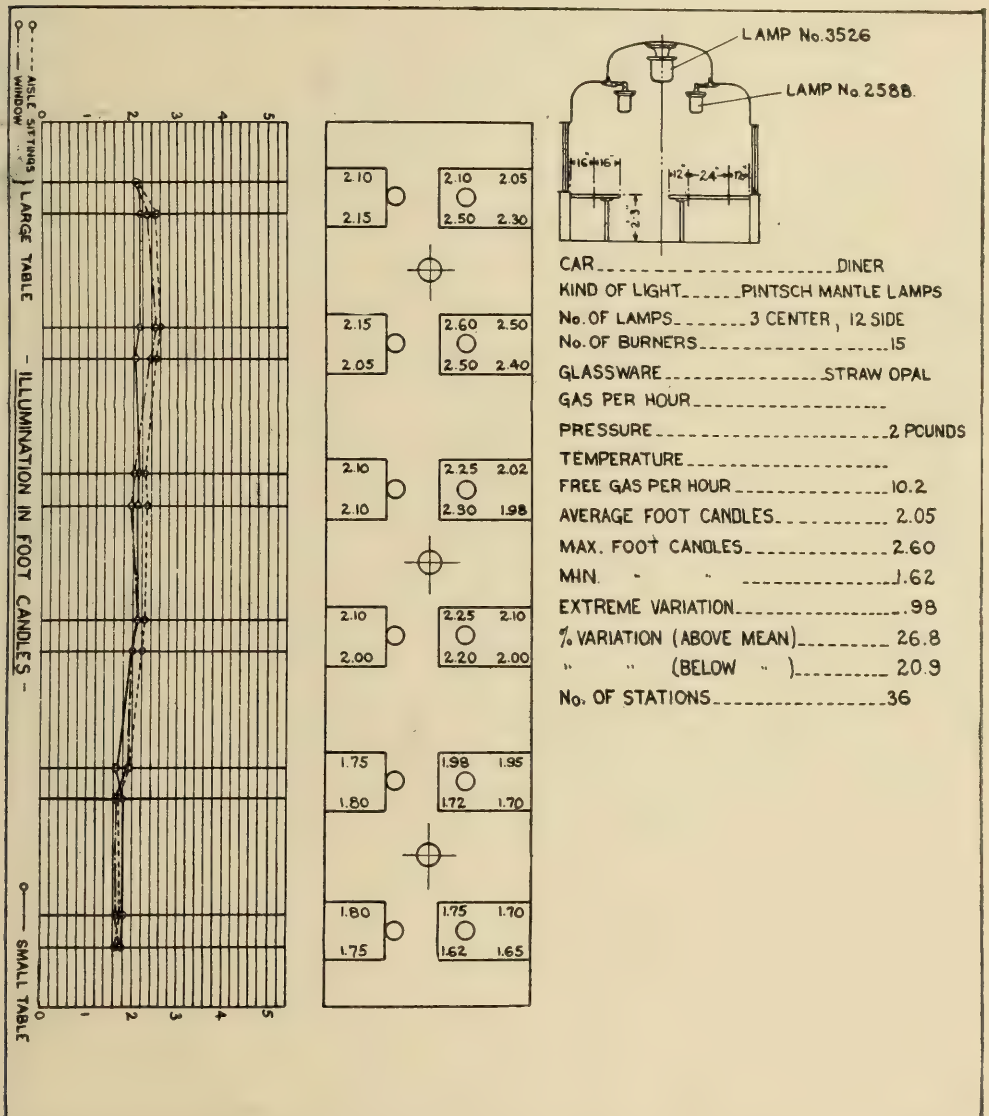

Fig. 14.—Illumination of dining car by mantle lamps.

15 watt tungsten lamp while the broken line shows the candle-power of the old type using a 20 watt metallized filament lamp.

The diagram, Fig. 12, shows the results obtained by the use of this lamp with center lamps on a sleeping car recently built. It will be noted that the illumination curve for both

aisle and window sittings is practically a straight line. Fig. 13 shows the interior of this car.

Dining cars require special treatment—a concentrated illumi-

Fig. 15.—Interior of dining car with mantle lamps.

nation on the tables with a general illumination which will show the interior decoration without detracting from the table illumination.

Fig. 14 shows how this can be done with gas lighting by the

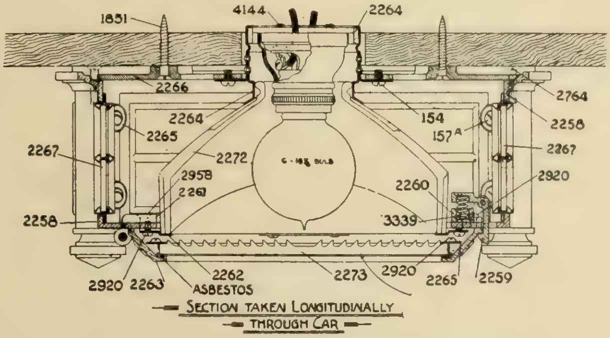

Fig. 16.—Section of dining car lamp.

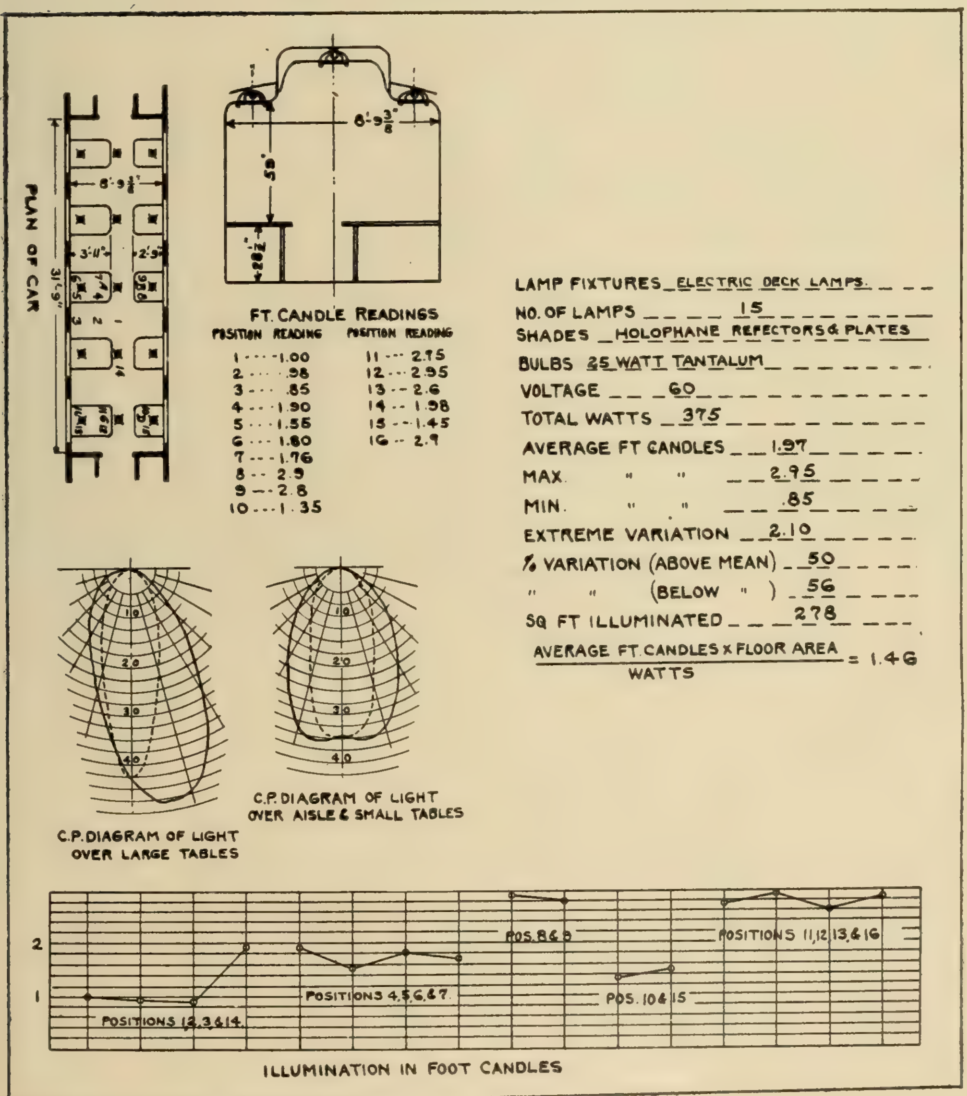

Fig. 17.—Illumination of dining car by electric lamps.

use of proper fixtures correctly placed. Fig. 15 is a view of

the interior of this car showing the arrangement of the lamps.

A most satisfactory method of obtaining the proper lighting for dining cars has recently been developed. On the side deck over each table is placed a lamp containing a single electric bulb. Over the bulb is a concentrating glass reflector, which reflects the light in the plane parallel to the length of the table with an asymmetric distribution, as with the dining table seating four, the center of the lamp could not come over the center

Fig. 18.—Table illumination in dining car.

of the table. In the plane perpendicular to this, the distribution is symmetrical and concentrated; center lamps of the same type were provided for general illumination, having plates giving symmetric extensive distribution. A sectional view of this lamp is shown in Fig. 16.

Fig. 17 shows the results of illumination tests in a diner fitted with this type of lamp, Fig. 18 the illumination on one on the tables, and Fig. 19, an interior view of a car equipped with this type of lighting.

In the first installation the plates are placed flush with the ceiling, no lamp fixtures being visible. While this gives good re-

sults as far as table and floor illumination is concerned, it will be found that the ceilings are dark and the effect rather gloomy. Lamps have been designed which overcome this difficulty, the fixture being of the box type, dropped from the ceiling, with art glass panels to furnish ceiling illumination. Dining cars should be cheerful places, and concealed lighting with no apparent source of light does not give the proper effect.

Postal cars require greater illumination than those of any

Fig. 19.—Interior view of dining car.

other class, especially at the letter distributing cases. This is easily provided for with mantle lamps, the lamps at the cases being placed directly over the distributing tables, out of range of the clerk's eyes. In other parts of the car center lamps are used.

A test which was made recently on the lighting of two electrically lighted postal cars shows how easy it is to get a poor result at a greater expense than for a good result. One of the cars tested was fitted with continuous enameled reflectors of such

shape that the filament of the bulb was exposed, clear glass bulbs being used. The other car had the lamps fitted with individual reflectors of such shape that the bulb was completely hidden. The illumination diagram (Fig. 20), shows that the second arrangement really gave the best result in foot-candles per kilo-

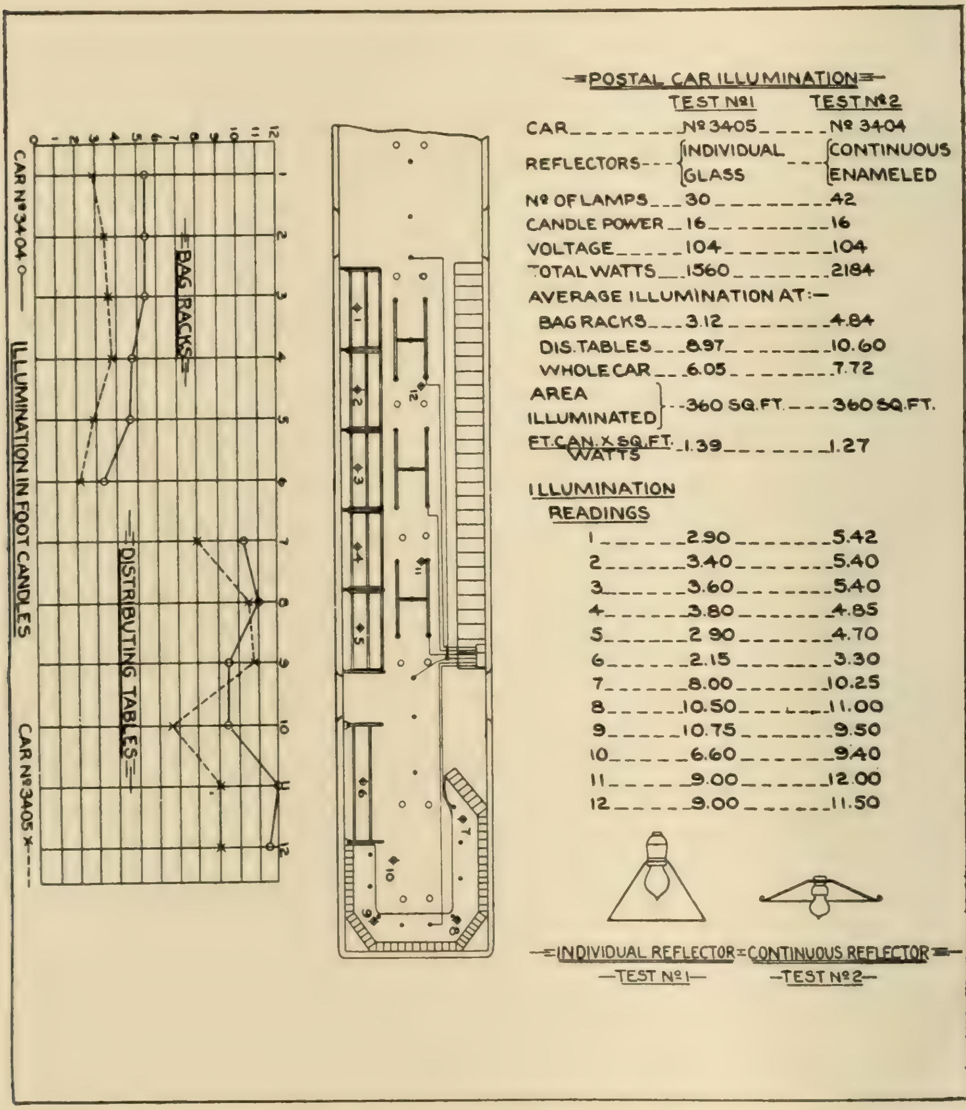

Fig. 20.—Illumination of postal car.

watt. How much better results it gave in actual service cannot be calculated.

Railroad officials are realizing that quantity of light does not always mean good illumination, and the best practice in car lighting compares favorably with efforts in other lines.

DISCUSSION.

Mr. Geo. S. Barrows:—I understand that all of these readings are taken on the horizontal plane; is that so, or do you make some on something different from the horizontal plane?

Mr. Hulse:—The readings for the illumination tests were taken in a manner to give the actual amount of light available for the purpose for which it was to be used. Readings in coaches are taken as follows: A table is used which supports the receiving disc of the illuminometer at the height of a paper held for reading, and fixed in its proper lateral position, there being two stations in each seat corresponding to the aisle and window sitting. A medium sized man takes his seat in the sitting at which the light is to be measured and finds by trial the best vertical angle to hold the paper for reading. The receiving disc of the illuminometer is turned to this angle and the reading made with the man still occupying the sitting. This gives us the effect of head shadows which may be thrown on the paper and the reading obtained shows just what light the passenger gets on his paper.

In dining and postal cars the readings are made on the horizontal plane at the height of the tables.

Mr. Barrows:—He takes his paper and moves around until he gets in the most comfortable position?

Mr. Hulze:—Yes; that is, as far as the angle which the paper made with the horizontal, but the edge of the paper was kept parallel with the longitudinal center line of the car.

Mr. C. H. Hunt:—Mr. Hulse spoke in some of his tests as using a pressure of two pounds per square inch. Can he tell us what that represents in tenths inches of water pressure?

Mr. Hulse:—Two pounds pressure per square inch is equivalent to a water column of 554 tenths inches.

Mr. F. N. Morton:—I think Mr. Hulse said that our ancestors did not pay much attention to their illumination. I was told by the then Engineer of the Pintsch Company that about twenty-five years ago that Company designed the well-known porcelain reflectors in use at that time for the 4-burner flat-flame lamps, and intended to throw a uniform illumination throughout the

length of the car. The space immediately under the burner was to receive less reflected light, the maximum point of reflected light being half-way between two burners. In that way they aimed to get uniform illumination throughout the car. They did not have illuminometers in those days; the best they could do was to have a man pull his hat over his eyes, and then sit in different parts of the car and note the ease with which he could read. When he got to such a point that he could not distinguish any difference in his ability to read in different parts of the car, they considered that uniform lighting. The point is that they did pay some attention to that phase of it; they made a specialty of it.

Mr. Hulse:—I showed on one of the slides to-night the candle-power diagram of the four flame lamp with the reflector, which Mr. Morton speaks of, and the distribution is very good for a uniform illumination.

Mr. Geo. S. Barrows:—I would like to ask Mr. Hulse if the plates used in dining cars are unpleasant if a person happens to look up; is there much apparent glare from the diffusing plates underneath the lamps?

Mr. Hulse:—No, the plates are made with satin finish so that there is no glare; the plates are of sufficient size so that the intrinsic brilliancy is low.

Mr. W. H. Gartley:—The position that I have been in, in connection with car lighting, is not that you get too much glare in a certain direction, but that you are fortunate if you can find an angle at which you can hold your book or paper and get light enough to read by.

I believe there is no problem in illuminating engineering that has been, in the past, so carelessly worked out as railroad passenger car illumination, and if such a statement is true, it should be humiliating to our larger railroads, at least if not to the Pintsch Company.

As a commuter I have seen, day after day, during the season of early darkness, people in railroad cars failing in an attempt to read in a light just a little short of being sufficient to read by, give it up and then sit and blink at lights far too bright for anything but reading.

I do not agree with the speaker that the present cluster of flat flame burners are or can be located in a car so as not to produce a painful effect. If one travels, at night, in a regular coach from New York to Philadelphia, the effect of these lights shining in the eye is decidedly unpleasant.

This lecture by Mr. Hulse therefore is most interesting and welcome. It shows me that I was mistaken, that where I believed indifference to progress held sway, there is a most comprehensive and thorough knowledge of what should be done and how to do it. Mr. Hulse has given us a singularly clear example of the application of the principles of modern illuminating engineering to concrete practice; forcing conviction that his company is ready with proper solutions of railroad coach illumination problems of all kinds. That the railroads are taking advantage of this knowledge is illustrated by the figures given by Mr. Hulse of the introduction of mantle burners in the cars of this country. We remember the sighs of relief which greeted the introduction of these lights.

We can now see to read in these cars, but more should be done. We want the glare taken from the eyes of the non-readers, either by the use of green shades or by the box lamps described by Mr. Hulse. We want, I should say, just the reverse of what we have now in the cars lighted by the flat flame clusters. We are living just at the time to witness a revolution in railroad illumination, and I hope and expect to see this branch go as far ahead in the next few years as it has lagged behind in the last decade.

Mr. E. S. Pelling:—I would like to ask Mr. Hulse if continuous concealed lighting, directly over the seats, has been tried? I should think this method of illumination would give a better diffusion of light and be more appreciable by the passengers than the systems shown by the slides.

Mr. Hulse:—I do not think it has been tried, chiefly because of construction and operating difficulties.

Mr. W. J. Serrill:—Has this question of the movable reflector been worked out in practice? I can hardly conceive that a Railroad Company, if the reversible reflectors have been worked out in good mechanical shape, would consider it too much trouble

to reverse them at the end of a run. The car seats have to be reversed at the terminus, and the ventilators changed, and surely there is little more trouble involved in reversing the reflectors on the lights, if made so as to be easily reversible and fixed in the new position. It seems to me that the results obtained would be so satisfactory that such a scheme would be worth working out. If the matter was proposed in a theoretical way to a railroad manager, he might object to it, whereas if it was worked out practically, he might accept it.

Mr. Hulse:—I see several railroad men here whom I would like to hear from as to the practicability of such a scheme.

Chairman:—We would be glad to hear from some of our Pennsylvania Railroad friends; I see we have some with us.

Mr. H. E. Gough (P. R. R.):—In regard to reversing reflectors, I think this would not be looked upon with favor. One has to be with the railroad for a while, I believe in order to appreciate how difficult it is to accomplish some very simple things, such as this scheme appears to be, and I think none of us would care to recommend a trial until all other resources had been exhausted. I am looking for improvements largely along the line Mr. Hulse has shown as applied to a dining car; that is, a semi-concealed effect. We could not carry out such an elaborate scheme on coaches as shown for the dining car in question, but possibly something between that plan and the one mentioned by a gentleman a few moments ago involving a continuous reflecting trough in the deck of the car might be worked out satisfactorily. The central fixture I consider a tradition which has come to us from oil lighting days and which can well be dispensed with in many cases: I can hold out a little hope, I think, to our patrons by saying that the management recently instructed the Electrical Department to go ahead in a systematic manner with investigations and experiments with a view to improving the lighting of our cars. Heretofore the lighting has been left until the last thing, and the car designers have located the lights as best suited their convenience or taste without regard to illuminating efficiency. Manufacturers engaged in exploiting different lighting systems are working with the railroads on this problem so that we may confidently look for considerable

improvement in the near future. At the present time I consider those cars equipped with gas mantles to be the best lighted. None of our electrically lighted cars are, in my opinion, reasonably well lighted; either there is not enough light or there are so many exposed lamps in the line of vision as to make it more or less uncomfortable to the passengers. I believe the railroads are beginning to realize this fact and will take action for the better.

Mr. Hulse has stated that there is no danger from fire with the Pintsch system of lighting. I have always had some fear that there is danger, in fact this is one of the reasons why there is a tendency to go to electric lighting—to get away from combustible or easily ignited materials in cars.

We are obtaining quite satisfactory results in the use of Tungsten lamps in train lighting service. We have experienced considerable trouble on account of breakage of the filaments but this difficulty is becoming less serious, due partly to improvements in lamp construction and partly, I believe, to the use of what is known as the "hot filament" system. In this system the wiring is so arranged that in daytime the lamps are thrown across two cells of battery or a resistance is thrown in series with the lamps so that the filaments are raised to a temperature such that the filaments just begin to glow. This scheme appears to reduce the breakage, due to the fact that the Tungsten filament is less brittle when hot and furthermore the indications are that it eliminates, to a great extent, the snapping of the filament which often occurs when full potential is thrown on a cold lamp. The expansion of a Tungsten filament is quite considerable and all who have worked with Tungsten lamps have noticed the quick movement of the filament which takes place when the current is applied. By the use of the hot filament system, this strain occurs only once. We are not all agreed as to just how much merit there is in the hot filament system, which was developed on our Western lines, but the performance obtained to date indicates that the advantages outlined above are obtained.

Mr. Kirschberg (P. R. R.):—Mr. Hulse's paper deals with a problem which is concerning us greatly on the railroad at present; one to which we are giving a great deal of attention.

Mr. Gough has outlined to you our car lighting policy, and while we agree with Mr. Hulse's ideals to a certain extent, we feel, however, that car lighting is tending toward the use of the electric lamp. We are not entirely in accord with the idea of indirect lighting, or of totally concealed lighting in cars, the placing of fixtures which tend to successful illumination in cars having been fully considered.

Beside the question of the candle-power of the illuminants, there is also the question of distribution of light from the units themselves and the placing of the units to be considered. We feel sure that if lamps are so placed as to deliver the light where necessary, at the same time reducing the intrinsic brilliancy of the lamps to overcome any objectionable glare in the field of vision, we will be very successful. Our cars have rather dark interiors. Perhaps by using lighter interiors and placing the lamps somewhat higher than we are at present doing, using some kind of deck lighting to solve the problem, we can improve conditions in general. We are about to start a series of tests on cars equipped with all the different systems of lighting which we are using, and we hope to evolve a new scheme which will be more successful than any of them.

The previous speaker mentioned the success already attained in making a through run without a failure of light. We are now having success in that direction with electrically lighted cars, and have made a through run from Jersey City to St. Louis and return on a straight storage system, using Tungsten lamps and a 280 ampere-hour battery. The Tungsten lamp is now being used successfully in car lighting and we have a number of them on our Paoli locals running out of Philadelphia and on through trains; we are replacing a great many carbon lamps on our cars with Tungsten lamps.

The question of overcoming excessive breakage of these lamps on cars is one that is engaging our attention to a great extent, and we are working on a so-called "hot wire" system.

Mr. Gartley brought out a point, the significance of which has never been sufficiently impressed; that is, that many of our illumination schemes to-day are acceptable to us merely because we have become accustomed to them. Lighting has been princi-

pally a question of taste, and perhaps one of style, as an instance of which it has been the custom heretofore to place lamps in the center of the car. Under these conditions it is necessary to place a newspaper so that the light coming from the center line of the car may strike it at an angle to permit of reading. Were the lamps placed around the car so as to give a fairly even illumination along the sides and on either side of the aisle, with a somewhat lower illumination in the aisle, perhaps we would have a better scheme of lighting than we have to-day.

Mr. Hulse explained his methods of taking readings of illumination of cars as the effective illumination on a paper in reading position. After all, the plane on which illumination readings are taken is more or less a conventional plane, and the readings taken are only indicative of the illumination which is used. If the distribution in the car is such as to give the desired illumination at every point in the car, there is no reason, as I see it, why a series of readings on a horizontal plane should not show the best average value of the illumination produced.

There is one point which I would like to have Mr. Hulse explain. It is understood that when Pintsch gas is compressed, certain hydrocarbons drop and are not picked up again by the gas as it expands to pass through the lamp.

Mr. Hulse spoke of using a transport charged to a pressure of 100 atmospheres for use in charging cars on branch lines. Undoubtedly the higher the pressure to which the gas is compressed, the more hydrocarbons will be precipitated, and I would like to know what the ratio of the candle-power of gas compressed to 100 atmospheres, when it expands, is to the candle-power of the gas before the compression?

Mr. Hulse:—In reply to Mr. Kirschberg's question about loss of candle-power due to compression of Pintsch gas to 100 atmospheres, I would say that we have found there is practically no difference in the candle-power of the gas after it has been compressed to 100 atmospheres from its candle-power after compression to fourteen atmospheres.

About the method of taking illuminometer readings. What we want to find in our tests is the light available at each point for the passenger's use, and to determine this accurately, actual

conditions should be duplicated in the tests. In order to read, the book or paper must be held at an angle to the horizontal, so in making the tests this angle was taken for the test plane. Where the light is used on a horizontal plane, as in a dining or postal car, the test plane is horizontal. In a coach, tests made with the test plane horizontal will show a distribution of illumination with the maximum at the center of the car, while the maximum useful illumination is at one end of the car. If the car is fitted with center lamps some distance apart, the horizontal plane will show, at stations between the lamps, effect from both the lamps in front as well as the lamps behind, while, as a matter of fact, the lamp in front does not produce any effect on the passenger's paper except for sittings nearly opposite the lamp.

Mr. Kirschberg:—There might be an advantage in being a small man under those conditions.

Mr. Gartley:—What is the diameter of those tanks that carry the 15 atmospheres?

Mr. Hulse:—The diameter of the standard tank is about 21 inches outside diameter, and 9′ 6″ long.

Mr. Gartley:—Has any of the Pintsch gas been shipped in large tank cars?

Mr. Hulse:—Yes.

Mr. Gartley:—Could you give a description of that?

Mr. Hulse:—The outside diameter of the standard holder is 21 inches, 9′ 6″ long. The working pressure is 10 atmospheres, or 147 pounds per square inch. Each holder is proved with a hydraulic pressure of 600 pounds.

Mr. Gartley:—Are they carried in the rear part of the train?

Mr. Hulse:—Yes. Most of the transport cars are equipped with our works storeholder, which is 4′ 8″ in diameter and 19 ft. long, with a capacity of 265 cubic feet per atmosphere. These holders have welded steel shell with spherical heads welded in. They are used with a working pressure of 14 atmospheres. We also have a number of transport cars equipped with a welded steel holder 8 ft. in diameter and 36 feet long. This has a capacity of 1,700 feet to the atmosphere or nearly 24,000 cubic feet at 14 atmospheres.

I do not wish to go on record as being in any way opposed to electric lighting, because our Company believes in electric lighting, and that is going to be used to a greater extent in the future than in the past. We believe in it sufficiently to agree to furnish electric light to railroads at a stated rate per car, furnishing all equipment and attending to its proper operation. At present we are using axle light equipments. We have a large force of men located at every railroad center in the country who are available for the care of these cars, and with this organization are able to take care of the operation of the cars more cheaply than the railroads can.

The factor of cost of course enters largely into the car lighting question and as the actual cost of gas lighting is about one-third that of electric light with most satisfactory results as to efficiency, its use is bound to be continued.

As far as the safety of the Pintsch gas goes, we can only stand on the record. I do not believe that an instance can be cited in which Pintsch gas was responsible for a fire following a railroad wreck.

Mr. J. D. Israel:—I move that the Section extend a hearty vote of thanks to Mr. Hulse for his interesting paper.

Mr. W. H. Gartley:—I want ot second that motion. I think this is one of the most important subjects that has come before this Society, and I hope that there will be reported the full discussion that we have had, and that each gentleman will see that his portion of the discussion is sent back to the Secretary after it is revised.

Of course the Society of Car Lighting knows more about these things than the Illuminating Engineering Society, but this seems to me to be a new branch to us, and it is one in which the illuminating engineers and the public are commonly interested; but I may say this, that if this paper gets into the Proceedings of our Society, it will have a very wide circulation.

There is scarcely a single meeting of the Board of this Society at which we are not asked to pass upon the exchange of various periodicals with the different Colleges and Societies all over the country, and I think this will be a branch that will do us a great deal of good.

Chairman:—The motion has been made and seconded that a vote of thanks be tendered Mr. Hulse; those in favor please signify in the usual way. So ordered.

I want to announce at the next meeting of the Section on January 21st, 1910, the subject will be:—"The Standard of White Light," by Dr. Herbert E. Ives, of the National Electric Lamp Association, and I extend on behalf of the Section a cordial invitation to every guest who is here tonight to be present with us, to hear Dr. Ives, and we will be glad to see any of you who are not members of the Society join with us.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. V. FEBRUARY, 1910. NO. 2

MINUTES OF COUNCIL MEETING.

MEETING OF FEBRUARY 10, 1910.

A meeting of the Council was held in the Engineering Societies' Building, New York, on Thursday, February 10, 1910. There were present Messrs. E. P. Hyde, president; W. H. Gartley, W. Cullen Morris, V. R. Lansingh, J. S. Codman, C. O. Bond, Bassett Jones, Jr., L. B. Marks, Preston S. Millar, general secretary. E. N. Hyde was present by invitation. The reading of the minutes of the previous meeting was dispensed with.

The general secretary submitted a report showing cash on hand January 1, $960.87. January receipts, $2,707.87; disbursements, $1,137.58; cash on hand February 1, $2,531.16. Total number of members on roll, 1,047. Total number of members having paid dues during January, 356. Bills aggregating $676.77 were presented and ordered paid, subject to the approval of the Finance Committee.

The following proposals for amendments to the By-Laws, having had preliminary hearing at the November meeting of the Council, were read and approved:

Art. 3, Sec. 6. Omit sentence reading, "This instruction shall be printed with the list of applications published in the TRANSACTIONS."

NOTE:—The remaining sentences of Section 6 should then bear a notation referring to Section 3 instead of to Section 4 of the Constitution.

Art. 4, Sec. 5. Change last two sentences, making them read as follows: "At the expiration of two months thereafter, if still in arrears, he shall be notified that his name will be presented to the Council as delinquent, if the dues are not paid within one month. If the member continues delinquent, the

Council shall drop him from membership at the regular meeting held in October."

Art. 9, Sec. 1. Change *shall* to *may*, making the first sentence read, "Upon petition for the authorization of a section of the Society, the Council *may* accord such authorization if the necessary membership exists within the locality specified in the petition."

It was resolved that the entrance fee be waived until June 15, 1910, and that notice of this fact be communicated to the Section Secretaries.

The President announced and the Council approved the appointment of the following committees for the year 1910:

Editing and Publication: G. A. Wardlaw, E. L. Elliott, and Preston S. Millar.

Board of Examiners: A. H. Elliott and Preston S. Millar.

Nomenclature and Standards: A. C. Humphreys, chairman; J. E. Woodwell, secretary; Louis Bell, Andre Blondel, Hans Bunte, John W. Howell, E. P. Hyde, A. E. Kennelly, John B. Klumpp, Vivian B. Lewes, L. B. Marks, Edward L. Nichols, C. C. Patterson, F. Schniewind, C. H. Sharp, W. D. Weaver, E. B. Rosa.

Advertising: VanRensselaer Lansingh, chairman; F. B. Rae and Joseph D. Israel.

Division of Membership: E. L. Elliott, chairman; Louis Bell, Bassett Jones, Jr., and George C. Keech.

The president presented a proposal calculated to increase the activity of the Society in disseminating knowledge of illuminating engineering. His plan contemplates a course of lectures by authorities on each of the various aspects of illuminating engineering, the lectures to be delivered under the joint auspices of the Society and of some university, and to form a post-graduate course.

It was then resolved that the president shall appoint a committee, of which he shall be the chairman, to investigate the feasibility of establishing such courses, and that such committee shall report definitely to the Council.

Upon request of the Council, the president announced that he would appoint later the following committees:

Section Development.

Progress. (To report at the Annual Convention).

New Members. The members of the last named committee are to report plans of campaign to the Council before taking action.

MEMBERS ELECTED FEBRUARY 10, 1910.

GIEB, W. V., 121 East Baltimore Street, Baltimore, Md.

MEYER, FRANKLIN, J., Westinghouse Lamp Co., Bloomfield, N. J.

MEEK, S. G., 604 Riverside Drive, New York, N. Y.

KNOWLES, R. W., 3267 Locust Street, Philadelphia, Pa.

LEE, T. FRED, 514 Atlantic Avenue, Boston, Mass.

MANN, HOWARD E., Montreal Light, Heat & Power Co., Montreal, Canada.

FRANK, S. S., 50 Church Street, New York, N. Y.

McNABB, B. G., Montreal Light, Heat & Power Co., Montreal, Canada.

MOULTON, WALTER R., Glen Ellyn, Ill.

WHEELER, HARVEY B., 3149 W. 14th Place, Chicago, Ill.

WICKENDEN, WILLIAM E., was reinstated as a member.

OBITUARY.

C. J. TOERRING.

Mr. Christian J. Toerring, a member of the Philadelphia Section and an electrical engineer of much prominence, died at his home in Philadelphia on Friday, April 22, 1910. He was a pioneer in bringing the enclosed arc lamp to its present state of perfection. Although but 39 years old, Mr. Toerring ranked among the first in his profession.

He was born in Denmark, but was brought to this country when a child. He was educated at the University of Illinois, taking his engineer's degree by post graduate work at Cornell. He went to Philadelphia in 1899 and soon made a name for himself as a manufacturer of arc lamps. He was a member of the Franklin Institute, the American Institute of Electrical Engineers, and the Illuminating Engineering Society.

He received highest awards at the National Export Exposition, Philadelphia, 1899, Paris Exposition, 1900, Buffalo Exposition, 1910, also the Edward Longstreth Medal of Merit by the Franklin Institute in 1903.

CAMPAIGN FOR MEMBERSHIP.

The Council of the Society has appointed W. H. Gartley, of the United Gas Improvement Co., Philadelphia, Pa., H. B. Dates of the Case School of Applied Science, Cleveland, O., and J. Robert Crouse of the National Electric Lamp Company, Cleveland, O., (Mr. Crouse, chairman), as a Membership Committee to increase the membership of the society. It is the intention to make this campaign an active but a conservative one, through the careful preparation of a list of those to whom the society can be of great service and who really need the society in their work.

With this thought in view, your co-operation is now sought for information of the proper men for solicitation by this committee. The committee would thank you for the names of a few of your acquaintances, including their address and business connection, in order to call to their attention the usefulness of the society.

The committee will also be grateful for any suggestions on the subject of increasing the membership of the society.

A paper presented at a meeting of the Philadelphia Section of the Illuminating Engineering Society, Philadelphia, Pa., January 21, 1910.

LUMINOUS EFFICIENCY.

BY HERBERT E. IVES.

The problem of determining the efficiency of the artificial processes of light production has engaged the attention of investigators ever since the definite beginnings of the science of illumination, early in the last century. The problem is a complicated one, almost solely because one of its chief factors is not physical, but physiological. The product of the process of conversion of energy,—light,—is something the quantitative measurement of which, in the case of illuminants, depends upon subjective sensation. The difficulties imposed by the nature of light, considered as a subjective sensation, have been such that the quantities most generally used in attempting to make scientific comparisons of illuminants have been at best approximations. These quantities have in fact been arrived at by largely disregarding the physiological side, and, just in proportion to the amount of this disregard, are they unsatisfactory.

Within the last few years considerable work has been done on the relation between radiation and light. Following the pioneer work of Langley and Koenig, such men as Fery, Guillaume, Eisler, Drysdale, Nutting, and others have made contributions to the general problem. As a consequence, it is now possible to make definite and satisfactory comparisons of the efficiencies of artificial light sources, where by "efficiency" is understood the ratio employed in the measurement of any transformation of energy, namely, the ratio of the useful work rendered by the process to the energy put in, each being measured in appropriate units. Curious as it may seem, in the estimation of efficiencies the method of electrical engineering has been more scientific than the methods generally used by scientific writers. "Lumens per watt" is an exact measure of efficiency, while "Luminous efficiency" is not. It has only been by coordinating the conception of luminous efficiency with lumens per watt measurements, by including the physiological factors,

that progress has been made possible in the scientific study of efficiencies. As an illustration, it is now possible to express the common candles per watt of the commercial incandescent lamp in terms of an absolute efficiency. The "4-watt" carbon lamp, for instance, has an efficiency of 0.4 per cent. The standard of comparison is the most efficient possible light source; and the ratio of the lumens (or candles) per watt of two illuminants is the ratio of their absolute efficiencies. This is obviously as it should be, but in the "luminous efficiencies" which have figured in scientific investigation, such has not been the case.

In the present paper are outlined the scientific methods which have been employed at one time and another in comparing the efficiencies of light sources. The methods of estimating and the values obtained for "luminous efficiency" and for the "mechanical equivalent of light" are noted as briefly as possible, chiefly for the purpose of showing in what way they are inadequate for our present more exact needs, and in how far they have assisted toward the more satisfactory idea of efficiency now possible. The writings and experimental work of several men are drawn upon freely, in particular the excellent discussion of Drysdale.[1] The object here is not so much to present original work, of which there is very little, as to aid in clearing up the confusion which exists at present, and to bring to the solution of the scientific side of the problem some pieces of work which have only recently become available, or whose availability has not heretofore been realized.

The discussion centers about four topics. 1st, "Radiant Luminous Efficiency," the most frequently used basis of comparison of light sources. 2nd, "Total Luminous Efficiency." 3rd, "The Mechanical Equivalent of Light." 4th, "Reduced Luminous Efficiency," the term applied by Drysdale to the more rational and exact basis of comparison which it is the object of this paper to present and emphasize.

Before considering the subject in detail, warning should here be given that a multiplicity of similar sounding terms will be met with. The resulting confusion is painful. Only after making a special study of the subject can these terms be clearly

[1] Illuminating Engineer, London, Vol. 1, 1908.

differentiated by the mind, and used correctly. At the conclusion, the suggestion will be made that the majority of these confusing terms be altogether discarded.

RADIANT LUMINOUS EFFICIENCY

The term "luminous efficiency" is usually applied to the ratio of a certain fraction of the radiated energy to the total radiated energy. It is also sometimes applied to the ratio between this fraction of the radiated energy and the total applied energy,—a more or less different quantity. In order to make clear the relationship of the various quantities involved in either use of the term "luminous efficiency," let us consider the transformations undergone by the energy supplied to a light source.

The total applied energy is given out in three forms, represented below:

Total applied energy {
- *Conduction*, as through supports, piping or wiring.
- *Convection*, heat carried off by currents in the surrounding medium.
- *Radiation*, electro-magnetic waves in the ether.

Of these, conduction and convection contribute nothing to the production of light. Radiation has been commonly divided into three parts:

1. The long, infra-red, or heat waves, to which the eye is not sensitive.
2. The intermediate waves, constituting visible radiation.
3. The short waves, called actinic, or ultra-violet, which do not cause the sensation of light in the eye.

These are shown diagrammatically in Fig. 1. If we desig-

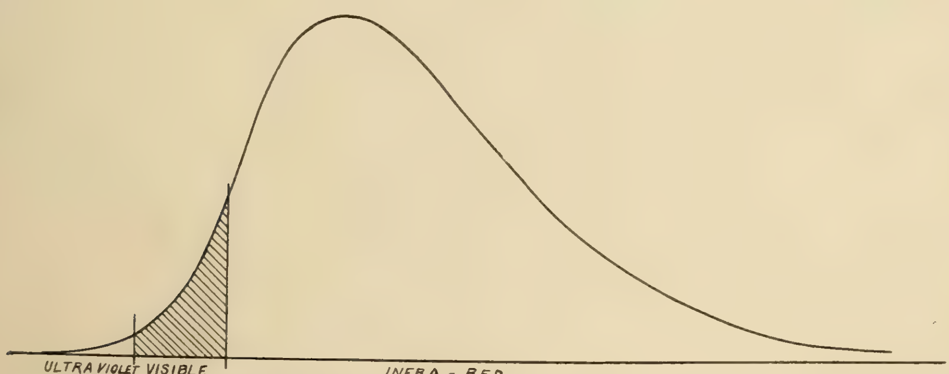

Fig. 1—Energy distribution of black body radiation.

nate the total applied energy by Q, the total radiated energy by R, and by L that portion of the radiated energy appreciated by

the eye as light, we can express the three efficiencies which have usually been employed, as follows:—

Efficiency of transformation of applied energy into radiation	R/Q
Ratio of visible to total radiation	L/R
This has been called "radiant efficiency" by Nichols to distinguish it from	
Ratio of visible radiation to energy input, or "total efficiency"	L/Q

Inspection of these ratios shows that in order to express them as percentages L, R and Q should be in the same units. Two consequences of this are to be noted. First, since the property of light with which we are most concerned, namely its visual intensity, is not directly proportional to quantity of radiation, but varies with wave-length, therefore light, considered photometrically, cannot be expressed as a simple energy quantity, as can R and Q. This difficulty has long been realized, but has apparently been regarded either as of no consequence, or as impossible to meet. Consequently the physiological factor entering (visual sensibility) has been considered only to the extent of recognizing certain largely arbitrary boundaries to the radiation which is appreciable by the eye. For L is taken the quantity of radiated energy lying between certain wave-lengths, usually chosen as $.76\mu$ and $.38\mu$, although we find wave-length limits of $.80\mu$, $.70\mu$ and $.40\mu$ sometimes taken. Radiant efficiency then becomes the ratio of that radiated energy between the chosen spectral limits, to the total radiated energy. It is obvious that the values will depend upon what wave-length limits are taken, a serious objection to the method. This visible portion of the radiated energy should be called "light" only in the sense that it is appreciable by the eye; great care should be taken not to think of it as light quantity as derived by photometry. The importance of this caution will become evident as we proceed. It is sufficient to state here that by this criterion two illuminants could each have 100 per cent. efficiency but differ, due to difference in color, in their candle-power per applied watt by several times.

The second consequence of the limitation imposed by the units is that the radiant efficiency L/R is more often determined than the total efficiency L/Q. The two quantities L and R, as we

shall see, are measured in the same way, by radiation meters, so that determination of their absolute values is not necessary to obtain their ratio. On the other hand, L and Q are usually measured by different means, L by radiation meters which do not immediately give absolute energy values, Q by watt-meters, in the case of electric lamps, or equivalent methods with other illuminants. To obtain the total efficiency, L therefore, as well as Q, must be obtained in energy units.

Two general methods have been used to determine radiant luminous efficiency.

First,—by exposing a radiation meter (thermopile, bolometer, pyroheliometer, etc.) first to the total radiation R and then to the visible radiation L.

Second,—by measurement of the distribution of energy along the spectrum, and subsequent integration of the whole area as plotted from the observations, and of the visible portion.

In using the first method it is necessary to decide on some means of separating the visible from the total radiation. One of the earliest means was the use of absorbing screens, opaque to the infra-red rays. In this way alum and water, and later ferro-ammonium sulphate have been employed, and numerous values of L/R obtained. At best absorbing screens are unsatisfactory, for their limits of transmission are not well defined, and as is evident from Fig. 1, a slight shift of the line of separation of "visible" and "dark" radiation can make a large change in the value of L. Furthermore it has been found by Nichols and Coblentz that the results obtained by water, alum, and iodine absorption cells are not trustworthy because the transmission coefficients are not as usually assumed. Drysdale finds the ferro-ammonium sulphate solution chemically affected by radiation and hence also unreliable. For these reasons values obtained by the use of absorbing solutions are only of interest historically.

A better method for performing this separation is that of Angstrom. A spectrum is formed, an opaque screen placed over the portion not desired, and the energy re-condensed upon the energy measuring instrument. This has been used by Ang-

strom and by Ingersoll, and their figures are probably the only ones of value obtained from direct measurement of L and R.

Radiant efficiency by the second or spectrum integration method has been determined by Tyndall, Langley, Nichols and others. The method demands sensitive instruments, as well as considerable time and labor, but it is probably as satisfactory a one as any.

In the table below are a few values of radiant luminous efficiencies, as determined by the means which are apparently exact and reliable.

TABLE I.

"Radiant Efficiencies." Ratio of radiant energy between wave lengths $.38\mu$ and $.76\mu$ to total radiant energy.

Source.	Observer.	Date.	Method	L/R
Hefner	Angstrom	1903	Opaque Screen..........	.0096
Nernst	Ingersoll	1903	" "	.0417
Acetylene	Angstrom	1903	" "	.055
"	Nichols	1903	Spectrum Integration....	.03 to .04
"4-watt" Carbon lamp	Ives and Coblentz	1909	" "	.018

Before passing on to the discussion of "total efficiency," the exact meaning and limitations of the radiant efficiencies tabulated above must be emphasized.

The value of L/R gives us this information:— The same light, both as to quantity and distribution in the visible spectrum, could be obtained from the fraction L/R of the radiated energy. This information, although of considerable value as giving us an approximate idea of the wastefulness of artificial light production, is incomplete, for it recognizes no difference in the illuminating value of the visible radiation depending on its color or quality. Illuminants in which all the radiated energy lies in the visible spectrum would be rated alike as 100 per cent. efficient. A red light and a yellow light of equal energy output would be rated the same, although the latter could be a hundred times as bright as the former, because of the distribution of sensibility in the eye. Efficiency in an illuminant does not follow simply from its radiation being concentrated in the visible region, but also to a very large degree from that radiation being advantageously placed in the visible region. A practical re-

sult of this is that the ratio of the candles per watt of two illuminants is not that of their luminous efficiencies, for the two candlepowers are determined in part by the different distribution in the visible region of the radiation, as well as by the amount of visible radiation.

The 100 per cent. efficiency of this method, to which other efficiencies are compared, therefore, merely expresses the condition that all the radiant energy lies within certain limits. It gives no information as to how advantageously the radiation might be placed in that region. It gives in fact only a rough measure of real efficiency.

TOTAL LUMINOUS EFFICIENCY.

To obtain the radiant efficiency it has only been necessary to know the ratio of luminous to total radiation. If, however, we know L, the luminous energy, in energy units (assuming the energy input similarly measured, as is usual) we are in a position to find the total efficiency L/Q, or the proportion of the total applied energy (as distinguished from the radiant energy) which would be sufficient to give the same light, in quantity and spectral distribution, as the measured illuminant. The total efficiency is, like radiant efficiency, a pure number; the difference being that by making the comparison between L and Q, instead of L and R, we obtain a value in which the losses by conduction and convection are taken account of.

Measurement of the radiated energy in absolute units has usually been done in connection with determination of the mechanical equivalent of light, which is treated in the next section. From values for the mechanical equivalent we obtain the energy in visible radiation corresponding to a unit of light flux. Knowing the energy input necessary to give the unit of light flux we are in a position to determine the total efficiency. We will anticipate the results given in the next section to the extent of showing by one illustration, the derivation of "total luminous efficiency." Thus, taking a value given by H. Lux for the consumption of energy by the Hefner, as 115 watts per mean spherical candle, we obtain for its total efficiency .121/115 or .001, as against .009 for the radiant efficiency, indicating large

losses by conduction and convection. With an incandescent lamp these losses are quite small, so that total and radiant efficiencies are nearly the same.

Values of total efficiency have much the same limitations as values of radiant efficiency. The standard of comparison, viz., the source of 100% efficiency, is the same quantity and quality of light as the source gives; that is, a part of the source itself. It is not compared with an outside, absolute standard of efficiency. There is too, no direct connection between total efficiency and lumens per watt.

THE MECHANICAL EQUIVALENT OF LIGHT.

Another means of obtaining a measure of the efficiency of light production is by determination of the "mechanical equivalent of light." By the "mechanical equivalent of light" is meant the energy value of the visible portion of the radiation from a source giving a unit of light flux. An equivalent definition is: The energy value of the radiation of a source of 100 per cent. luminous efficiency, giving unit light flux. As the unit of flux the lumen has sometimes been used, more frequently the spherical candle. We shall in this paper as a rule use the spherical candle or 4π lumens, although the final values will be given in both units. The object of so doing is to make a little clearer the connection between current practical measures and the rational basis of comparison we shall derive. The lumen is of course preferable.

The mechanical equivalent of a given light (the necessity for this limitation will appear shortly) is expressed in watts per mean spherical candle. It must not, however, be confused with the total watts per candle, which is also a mechanical equivalent but in a more comprehensive sense.

The mechanical equivalent of a light is obtained in much the same way as radiant efficiency. The visible portion of the radiated energy (as before, an arbitrary line of demarcation must be made) is separated from the invisible and allowed to fall on a measuring instrument. Instead, however, of making a mere comparison of this energy with the total, its actual amount is measured. The same energy is then measured as light quantity with a

photometer, and thus the radiant energy corresponding to one spherical candle for the light source in question is determined.

Values for the mechanical equivalent of several lights have been determined by Tumlirz, Angstrom, Drysdale and others. The majority of these were determined by absorbing screen methods; if we discard these, for the reasons given above, there remain the following:

TABLE II.

Mechanical Equivalents of Light as Given by Several Illuminants.

Energy value of radiation from .76μ to .38μ corresponding to one spherical candle.

Source.	Observer.	Watts per Spherical Candle.
Hefner	Angstrom	.121
Arc	Drysdale	.0805
Nernst	"	.119

From this table we learn that the same quantity and quality of light as that given by these several sources could be obtained by the expenditure of the energy quantities given by the figures of the last column. Those quantities are of course much less than those necessary in practice because we cannot restrict the energy transformation to radiant energy in the visible region.

As to the characteristics and limitations of the "mechanical equivalent of light" one of the most important points to note is that the mechanical equivalent, as defined, is different for each light source. This has not been as well understood as it should have been. It has erroneously been assumed that the mechanical equivalent is a constant, and so some experimentors have thought to obtain total and radiant efficiencies simply by dividing the total energy input or total radiation, per mean spherical candle, by the value obtained by Angstrom. Eisler,[1] in an article which seems not to have been so widely noticed as it deserves, considered the distribution of sensibility in the eye, using Langley's values, and showed that the visible portion of the radiation from a black body increases several times in luminosity for the same quantity of radiated energy, as the temperature rises from 1000° to 5000°, due to the more advantageous distribution of the visible energy at higher temperatures. It should, indeed, have been obvious that the energy necessary to give a certain intensity in

[1] *Electrotechnische Zeitschrift*, 1904, p. 188.

a Hefner, with its very large amount of deep red, nearly useless as luminosity, would be greater than if the energy were concentrated toward the more luminous part of the spectrum. As an illustration of this error, Tumlirz concluded from the mechanical equivalent of the Hefner that the highest possible efficiency of light production must be about six candles per watt, while as we shall see fifty candles per watt is more probable.

It is therefore impressed upon us that the quality or color of the luminous radiation is a matter of the first importance. In consequence of disregarding it there exists no direct connection between radiant or total luminous efficiency, and the practical and satisfactory candles per watt. Nor do we arrive at any universal standard to which to refer efficiencies. The comparisons made possible by the determination of luminous efficiency are only rough. It is true in general that a source having a large value of luminous efficiency will be more efficient than one with a small; that the source having a small mechanical equivalent will be more efficient than one with a large; although in neither case is this necessarily so, and our knowledge is but qualitative. Exact quantitative comparisons of the efficiency of light sources is impossible from mere knowledge of luminous efficiency or the mechanical equivalent, so-called.

It is evident then that we have thus far arrived at no satisfactory basis for the scientific comparison of efficiencies. It is necessary in order to have this to so change our definition of luminous efficiency that it takes into account quality. We must carry the investigation of mechanical equivalents to the point of finding the minimum possible mechanical equivalent. We shall then find a direct relation between the new "luminous efficiency" or a light source, and its candles per watt, and our standard of comparison will be the light having that minimum mechanical equivalent. The manner of doing this is given in the next section.

REDUCED LUMINOUS EFFICIENCY.

Reduced luminous efficiency (so-called by Drysdale) substitutes for the pure energy quantity which represents "light" in radiant luminous efficiency, an energy quantity weighted accord-

ing to the capacity of the energy to produce the sensation of brightness. This makes the standard to which all efficiencies are referred, the light having the most advantageous possible distribution of energy, from the standpoint of the production of useful light. In place of considering the mechanical equivalents of light we are to be interested only in the mechanical equivalent of that most efficient possible source. With this we then compare, not the mechanical equivalents (in which we are not interested) but the watts per candle of our light sources. We obtain a ratio identical with "reduced luminous efficiency." Also, and as a consequence, the ratios of the candles per watt of two sources, is the ratio of their reduced luminous efficiencies.

The idea of reduced luminous efficiencies is arrived at by considering the relative luminosities of different portions of the visible radiation. The yellow-green or middle of the spectrum is the brightest, the red and blue ends, the least bright. Therefore, if we had a light source which not only radiated all its energy in the visible region (100% "radiant efficiency") but radiated it all at the brightest wave-lengths, we would have a source of 100 per cent. "reduced luminous efficiency."

Drysdale, following suggestions of Fery and Guillaume, attacked experimentally the problem of obtaining the mechanical equivalent of yellow-green light. Previously, however, Eisler without specifically mentioning luminous efficiency, had derived a value for this quantity indirectly from Tumlirz's values for the mechanical equivalent of the Hefner, using Langley's data on visual sensibility. The present writer, in calculating the luminous efficiency of the fire-fly, at the time ignorant of Eisler's work, arrived at a value of the mechanical equivalent of yellow-green light by using Koenig's values for visual sensibility, and radiation measurements of a glow lamp. The derivation of this quantity through our knowledge of visual sensibility will be given here, for the two reasons, that it makes possible the derivation of the mechanical equivalent in question from other known mechanical equivalents, and that it gives a method of ascribing values of reduced radiant luminous efficiency to all sources for which the distribution of radiation is known.

The sensibility of the eye to different spectral colors at dif-

ferent illuminations has been studied by Langley and by Koenig. Koenig's values are the more recent and complete. They have been put in convenient form by Nutting, and will be used here. The sensibility curve, according to Koenig, for the normal eye, for high intensities, and for a normal spectrum (uniform energy distribution) is given in Fig. 2. The ordinates give the relative

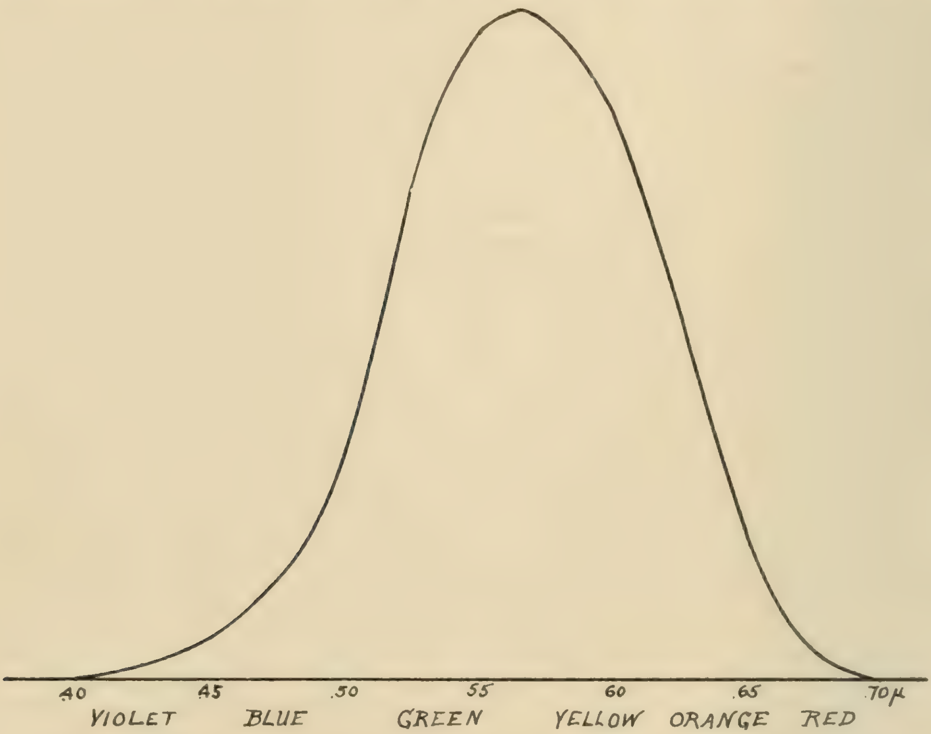

Fig. 2—Sensibility curve of the eye, for a normal spectrum at high intensities.

photometric values of the different colors of the spectrum. The maximum at $.565\mu$ is for convenience given the value unity. The maximum of this curve shifts toward the blue for low intensities,—the well-known Purkinje effect, and so in using these values the fact must be kept in mind that the results hold only for high intensities above the region where the Purkinje effect is marked.

If we know the complete radiation curve of a source, as determined by a bolometer or thermopile in conjunction with a spectrometer, we can assign to each wave-length its relative luminosity value by merely multiplying its energy value by the ordinate of the sensibility curve at that wave-length. We thus obtain a reduced energy quantity which is proportional at each

wave-length to the light value of the energy. The area of the reduced curve is then proportional to the luminosity of the source. Beyond the limits of the visible spectrum the value of the reduced energy is zero. If all the radiated energy were concentrated at .565μ (the most luminous part of the spectrum) the reduced area would be the same as the unreduced. This corresponds to 100 per cent. reduced radiant efficiency. It follows that the ratio of the reduced to the total energy curves gives the "reduced radiant luminous efficiency," where the standard of comparison is the efficiency of a source whose radiation is limited to yellow-green light at .565μ. In Fig. 3 are shown the total and

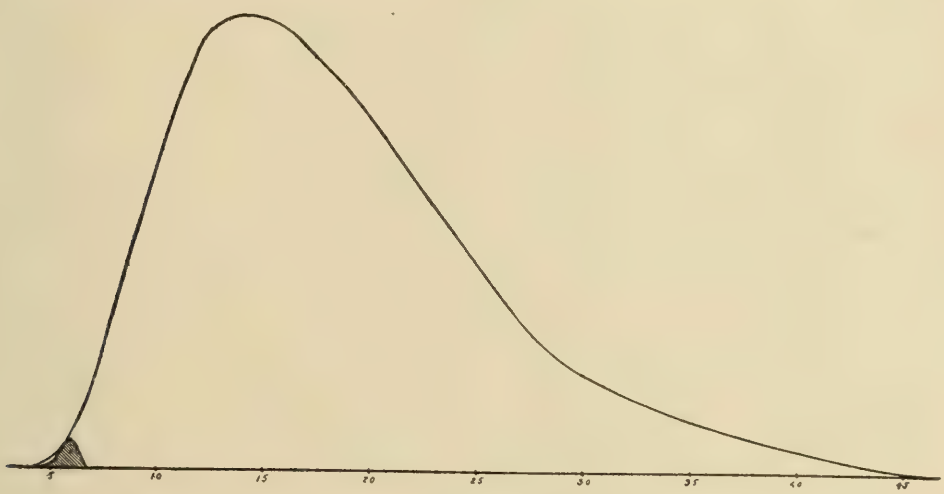

Fig. 3—Reduced luminous efficiency of a "4-watt" carbon lamp.

reduced energy distribution curves for a "4-watt" carbon lamp. The ratio of the shaded to the total area is the reduced radiant luminous efficiency. The necessity for restricting the statements to "radiant" efficiencies thus far is obvious.

Before proceeding further the following short table of reduced radiant luminous efficiencies will give an idea of the order of magnitude of this quantity.

TABLE III.

Reduced Radiant Luminous Efficiencies.

Hefner	.0018
"4-watt" carbon lamp	.0043
Black body at 6,000° absolute	.156
Fire-fly	.965
Monochromatic light, wave-length .565	1.000

The total area of the radiation curve is proportional to watts, the reduced area to luminous flux or spherical candles, the ratio of the two is proportional to watts per candle. If we determine the constant of this proportionality by measuring the radiated watts per candle, corresponding to a known "reduced radiant luminous efficiency" we can deduce the reduced luminous efficiency of any source from knowledge of its watts per candle. Determining this constant amounts to finding the mechanical equivalent of a light of 100 per cent. reduced radiant efficiency; in short, the least amount of radiated energy that will give one spherical candle.

Drysdale, with apparatus similar to Angstrom, made a direct determination with yellow-green light from an arc spectrum. His value was .059 watts per candle. This is the only direct determination thus far made where accuracy was striven for. By using the method employed by Eisler, it is possible to obtain values for this quantity from observations on other sources whose radiation curves or mechanical equivalents are known. Because of the difficulties in measuring the minute energy quantities represented by a narrow portion of the spectrum it is probable in the writer's opinion that more accurate values may be obtained by calculation from quantities that are less difficult to measure. This method of calculation of the quantity, which we shall call M, will now be given.

The simplest way of determining M (apart from a reliable direct measurement) is to know the radiated watts per candle of a source whose reduced luminous efficiency we also know. Thus the writer with Dr. Coblentz determined M from observations on a carbon glow lamp, on the assumption,—which cannot be far from true,—that practically all the applied energy is transformed into radiation. The reduced radiant luminous efficiency being .0043, and the watts per mean spherical candle being 4.83, it follows that a luminous efficiency of 100 per cent. would correspond to $.0043 \times 4.83$ or .021 watts per candle.

Recently through the kindness of Dr. E. P. Hyde the writer has had an opportunity to calculate the value of M from energy distribution measurements on three incandescent lamps whose watts per mean spherical candle-power were known. These

were an untreated carbon, a treated carbon, and an osmium lamp, used in an investigation on selective emission of incandescent lamps.[1] The distribution in the visible was obtained by comparison with a black body at known temperature (1690° absolute) whose distribution was computed from Wien's equation. The data were derived from the lamps at low voltages, corresponding to about 8½ watts per spherical candle for the carbon and about 5½ watts per spherical candle for the osmium, so that the proportion of visible to infra-red energy is quite small. As high accuracy cannot be expected under these conditions as when a large amount of energy is radiated in the visible region. The accuracy is also very dependent on the exactness with which the visible and radiometric measurements are joined. But with careful measurements the results should not be greatly in error.

From the osmium lamp, proceeding as with the carbon lamp described above, the value of M is deduced as .016 watt, from the untreated carbon .014, and from the treated carbon as .015 watt.

As far as the writer knows these are the only available experiments in which both the energy distribution and the quantity of energy are given. However, we have practically the same thing in those cases where we know both the mechanical equivalent and the shape of the radiation curve in the visible region. If we have the "radiant luminous efficiency" as well, we can determine the reduced radiant luminous efficiency, although this is not necessary to determine M. Knowledge of these quantities from the work of Tumlirz enabled Eisler to make probably the first recorded determination of M. In Fig. 4 is given the radiation curve of the Hefner lamp in the visible region ($.76\mu$ to $.38\mu$). The smaller curve is the reduced area proportional to luminosity. The reduced luminous efficiency of the visible portion of the Hefner radiation is the ratio of these areas or 0.19. (The "radiant luminous efficiency" or the ratio of this visible area to the whole, Angstrom found to be .0096; the product of the two quantities or .0018, is reduced radiant efficiency). Now the "mechanical equivalent" of the Hefner, or the quantity of

[1] Selective Emission of Inc. Lps. as Determined by New Photometric Methods.

energy radiated between these limits for one spherical candle is .121 watts. The product .19 × .121 or .023 watts is the value of M, in good agreement with the one derived from the

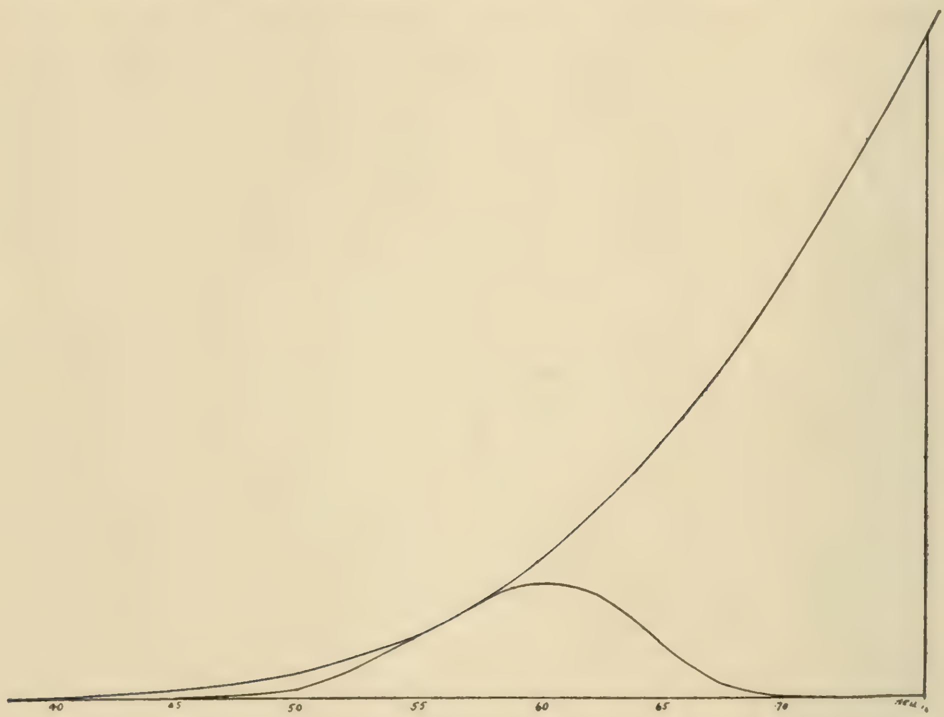

Fig. 4—Visible radiation of Hefner lamp.

"4-watt" incandescent lamp, but not with Drysdale's direct experimental value. Eisler obtained .017 watts. As his value was obtained through Tumlirz's work with absorption cells it does not deserve so great weight as the others, but since the same absorption cell was used to determine both the radiant luminous efficiency and the mechanical equivalent, the errors of the absorption method would be partly compensated for, and the order of magnitude of M cannot be far wrong.

Drysdale with the same apparatus determined the mechanical equivalent of "white light," using both a Nernst and a carbon arc. From these, values of M can be calculated as above, although Drysdale did not do so. For this purpose it is necessary to know the distribution of visible radiation.

Since these two illuminants have practically the visible energy distribution of a black body at appropriate temperatures, it will be sufficient to know the reduced luminous efficiency of the

visible portion of the black body radiation for various temperatures. Because of their general interest and application, the writer has worked out by this method the reduced luminous efficiencies of the black body for a series of temperatures, calculating the radiation curves from the equation of Wien. The values for the visible portion alone are given in Fig. 5. It is at

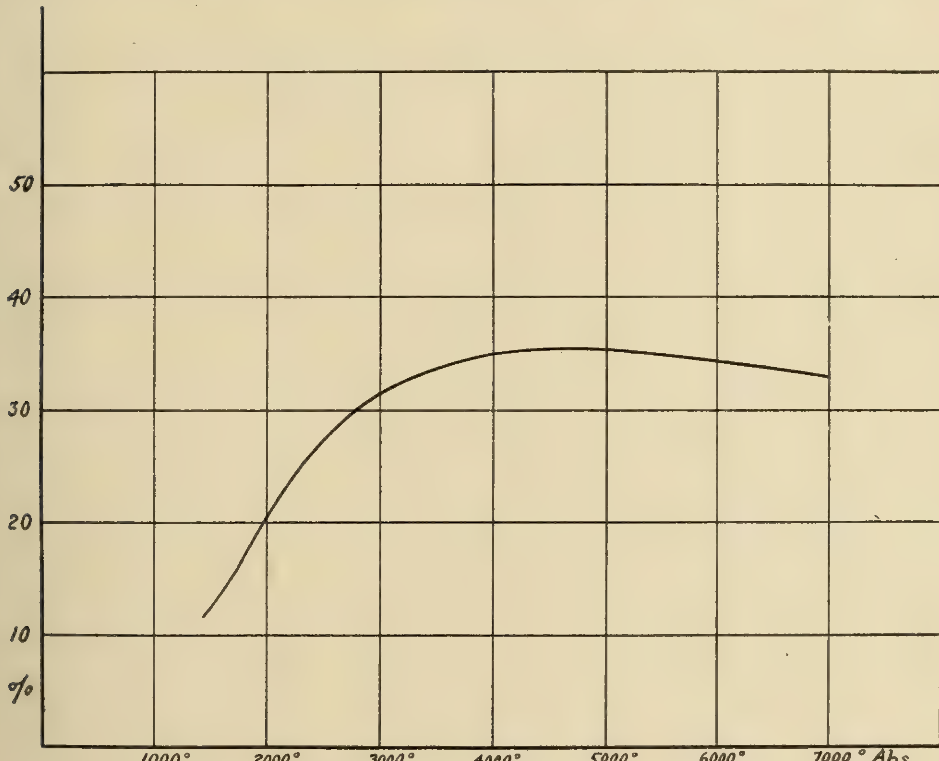

Fig. 5—Reduced luminous efficiency of visible radiation of black body.

once evident why the mechanical equivalent of light depends upon the character of the visible radiation, since the ordinates here represents quantities of light corresponding to the same energy quantity.

The values just obtained can be used in conjunction with the older "radiant luminous efficiency" to determine reduced values for the total black body radiation and illuminants of similar visual energy distribution. Drysdale has calculated the radiant luminous efficiencies of a black body (L/R), and the values are shown by the dotted line in Fig. 6. These have each been reduced according to Fig. 5, and the resulting reduced radiant efficiencies are given by the full line. The maximum efficiency

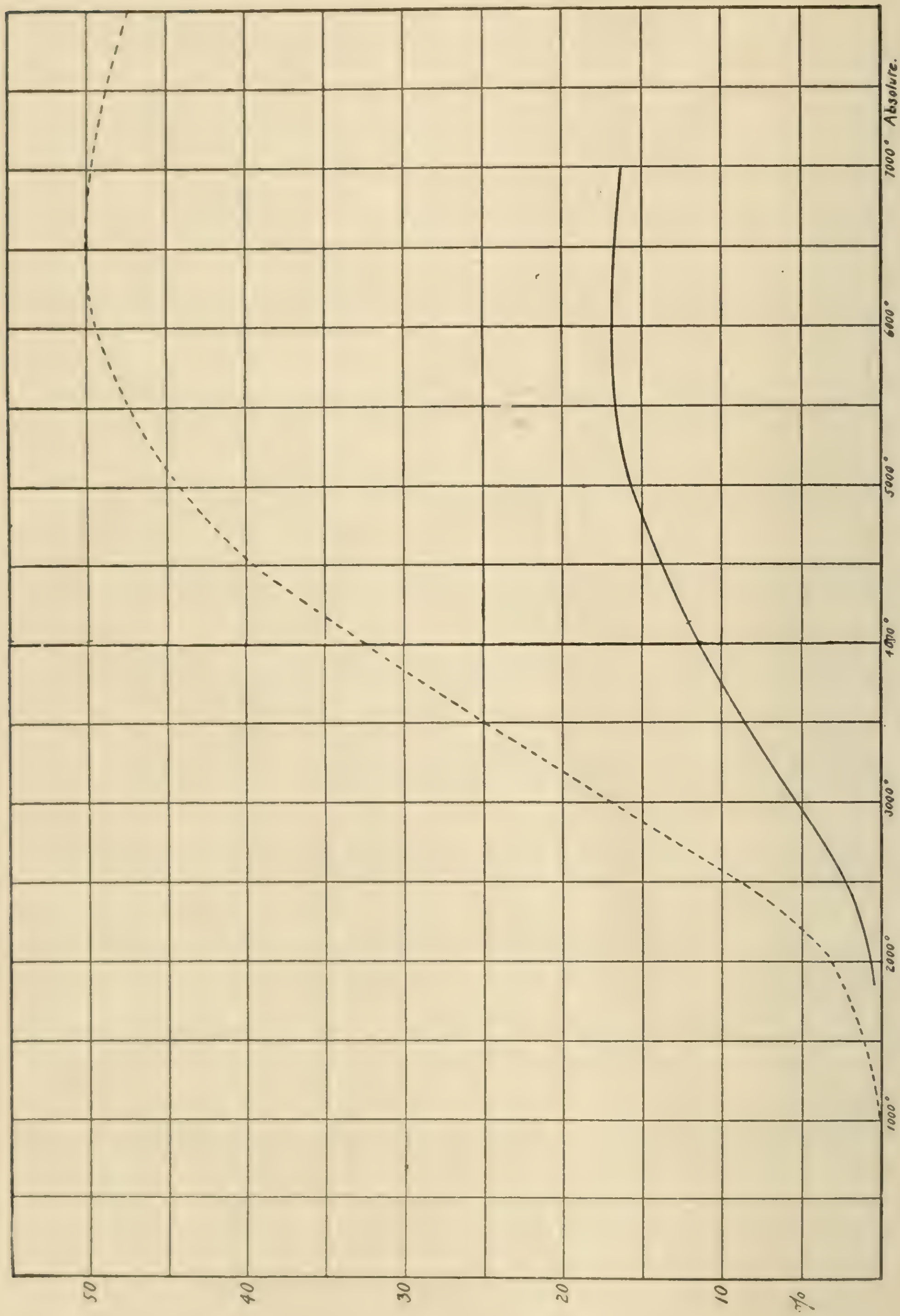

Fig. 6—"Luminous efficiency" and "reduced luminous efficiency" of black body.

is given at about 6000°. The radiation of the sun corresponds in its visible region closely to the black body at about 5000°, but the difference in color of the black body between 5000° and 6000° is so slight that we may say that the most efficient light a black body can give is white light. We shall return to the discussion of these values later.

To use these computations we note that the Nernst corresponds closely in visual distribution to an acetylene flame, which in turn is practically that of a black body at 2330° absolute.[1] Repeating the process we have applied to the Hefner, we find for the reduced efficiency of the visible radiation .255. This applied to the mechanical equivalent found by Drysdale for the Nernst gives .255 $\times$ .119 or .03 watts. Taking the arc as equivalent visually to a black body at 3000° absolute[2] we obtain .30 $\times$ .0805 or .024. These values are not consistent with the directly obtained value .059; probably, in the writer's opinion, because the chances of error in measuring the energy in the small band of green light were far greater than in measuring the whole visible spectrum.

We obtain therefore a number of values in the neighborhood of one fiftieth of a watt per candle, (with the exception of Drysdale's value of one-seventeenth). These values because of the manner in which they are obtained must be too high. We have assumed in deducing them that the candle-power measurements were made at high intensities, and, in the case of the incandescent lamps, that no energy is lost by conduction and convection. In practice photometric work is carried out at moderate illuminations,[3] where more energy is required, with illuminants of the kind we are considering, to give a certain amount of light measured by any of the present standards than at higher illuminations. The energy input would therefore need to be less under the high illumination conditions we have assumed. The amount of this connection is difficult to determine, being a function of the colors of the standard and the light tested. From some calculations made by means of Koenig's visibility curves for various

[1] In a direct comparison by Dr. E. P. Hyde, the value 2,326 was obtained.

[2] Obtained by spectrophotometric comparison of 10 amp. D. C. arc with acetylene.

[3] If a medium illumination were taken as standard, a sensibility curve with a maximum nearer the blue should be used. This would give smaller values for M.

intensities, using a "4-watt" lamp as the standard (*i. e.*, considering its candle-power a constant at all illuminations) the amount of this correction for any illuminant and conditions here considered would not appear to exceed 10 per cent. With regard to the losses by conduction and convection, they would also operate in the direction of making the energy assumed necessary for a certain light flux too large. These latter losses would be proportionally greater in the lamps run at lower temperatures.

The errors in the calculation of the quantity M being therefore all in the direction to make the obtained values large, the mean of these, viz., .024 watt per mean spherical candle is probably an upper limit. Giving small weight to the values obtained by Eisler and by Drysdale, for reasons already given, it appears that we can assign with some show of probability to the quantity M the value of one-fiftieth of a watt per mean spherical candle, or .0016 watt per lumen. Future work may determine this more accurately.

TABLE IV.

Values for the Mechanical Equivalent of the Most Efficient Light.

Method.	Watts per candle.
Application of Langley's sensibility data to Tumlirz's figures for the Mechanical Equivalent of the Hefner (Eisler) ..	.017
Direct measurement of yellow-green light (Drysdale)	.059
Application of Koenig's sensibility data to energy distribution curves or to mechanical equivalents (Ives)—	
Hefner (Angstrom's value of mechanical equivalent)	.023
Nernst (Drysdale's value of mechanical equivalent)	.030
Arc (Drysdale's value of mechanical equivalent)	.024
"4-watt" carbon lamp (distribution curve obtained by Coblentz)	.021
Untreated carbon lamp at 8.6 w. p. s. c. (distribution curve furnished by E. P. Hyde)	.014
Treated carbon lamp at 8.0 w. p. s. c. (distribution curve furnished by E. P. Hyde)	.015
Osmium lamp at 5.5 w. p. s. c. (distribution curve furnished by E. P. Hyde)	.016

This quanity is one of prime importance in comparing efficiencies. The derivation of "reduced luminous efficiency" has given us a rational basis of estimating efficiencies, but it is largely a means to an end. One object of studying efficiencies is to know

what efficiency should be attainable, and to compare our present ones with it. Future investigation should therefore devote itself not as formerly to accumulating values of luminous efficiency, but to obtaining more accurate values of M.

It would seem to the writer that the most promising method for doing this would be direct measurement of the light and energy of the very intense radiation from the green line of the quartz mercury arc. This gives much more energy for measurement than does a strip of continuous spectrum and may be easily separated from the other mercury emission lines by the use of absorbing screens. This line, wave-length $.546\mu$, does not correspond exactly to the maximum of sensibility according to Koenig, but is near enough so that only a small correction would be necessary. If this direct method proves unreliable, values can still be obtained through mechanical equivalents of "white" illuminants, by the use of the sensibility curve. These would always be subject to the errors of the sensibility curve, but a comparatively large change in the latter is necessary to make much difference in the resultant value.

Using this value of M, namely .02 watts per spherical candle, we can obtain some figures of interest. Referring to the values of reduced luminous efficiency for the black body, we see that about 17 per cent. is the maximum value at 6000°. Using Planck's equation instead of Wien's, a slightly smaller value results, namely 15.6 per cent. This, the most efficient black body, corresponds to .13 watts per candle or 7½ candles per watt. If all the radiation of the black body were confined to the visible region ($.76\mu$ to $.38\mu$) the reduced efficiency would be 34 per cent. (Fig. 5), or 17 candles per watt. The limits taken are however wider than necessary. A white light would be obtained from the radiation between wave-lengths $.40\mu$ and $.70\mu$. The reduced efficiency of this radiation is 42 per cent., or 21 candles per watt. It is therefore evident that the development of higher efficiencies is dependent on finding substances which not only will stand a high temperature but will radiate selectively in the visible region.

In the following table are collected figures for reduced luminous efficiencies and for candles per watt and lumens per watt.

Since the (total) reduced efficiencies are proportional to the candles (or lumens) per watt, it is only necessary to know accurately the reduced efficiency of one illuminant, for then the ratio of the candles (or lumens) per watt of other illuminants to it gives their reduced efficiencies. The reduced efficiencies of the last four on the list were so obtained.

It may be noted here that the definition of reduced luminous efficiency might be put in a slightly different form than we have used. Drysdale's manner of putting it is that the reduced luminous efficiency expresses the percentage of the applied energy which would be sufficient to give the same light quantity, had the energy been radiated as yellow-green light. The two modes of describing the quantity are exactly equivalent.

TABLE V.

Source.	Spherical candles per applied watt.	Lumens per applied watt.	Reduced luminous efficiency.
Ideal yellow-green source	about 50	about 625	100%
Fire-fly	?	?	96.5
Black body at 6000°	7½	95	15.6
Black body at 6000 between .70μ and .40μ	21	265.0	42.0
"4-watt" carbon lamp	.21	2.6	0.43
Tungsten	.63	7.9	1.3
D. C. Arc	1.1	13.8	2.2
Yellow flame arc	3.0	37.8	6.0
Quartz mercury arc	3.4	42.8	6.8

As was the case with so-called "luminous efficiency" it is necessary in giving "reduced luminous efficiencies" to note whether the efficiency is "radiant" or "total;" that is, whether we have considered merely the energy radiated, or the whole applied energy. In practice our knowledge is as a rule of the applied energy. In cases, however, where we are interested in the efficiency of the radiated energy we can obtain the radiant "reduced luminous efficiency" by measuring the radiated energy. In the case of the fire-fly for instance, we can study its radiation, but we do not know how much energy it has to apply to obtain a certain amount of radiation, *i. e.*, we cannot determine its total efficiency as applied watts per candle. Usually the knowledge we desire is of the total efficiency, or the ratio of the candles per watt to that of the most efficient light. If, however,

there is reason to believe that a large amount of energy is lost in the transformation from applied energy into radiation it becomes of interest to know the efficiency of the radiated energy alone. In such cases the radiant and total efficiencies are related to each other by the factor giving the efficiency of transformation of applied energy into radiated energy. This is a quantity easier to determine than either the so-called "luminous efficiency" or the "mechanical equivalent" for it is only necessary to measure the total radiation in watts,—not a small and difficultly measurable fraction of it.

As a consequence of developing the idea of reduced luminous efficiencies we find that in order to know all that is usually of significance about an artificial illuminant,—once the value of the constant M is determined,—we should determine—

1. Mean spherical candle-power.
2. Energy input.
3. Radiated energy.

From 1 and 2 we obtain the candles per watt, which we can compare with the candles per watt of the ideal source, or of the most efficient in white light. This comparison will usually be sufficient to answer our questions about relative efficiency. In certain cases it will be of importance to know where the chief waste of energy takes place. We learn this from "2" and "3."

SUMMARY AND CONCLUSION.

The meaning and values of the various quantities employed in the comparison of the efficiencies of light sources have been reviewed and criticized. It has been pointed out that the common technical measure of efficiency "candles per watt" or preferably "lumens per watt," is exact and satisfactory as far as it goes, while the usual scientific measure "luminous efficiency" is not. The weakness of the quantities "luminous efficiency" and "mechanical equivalent of light" is that they take no adequate account of the relation between the quality of the radiation and the efficiency, and that the values indicating the highest efficiency possible refer not to any common standard, but only to the particular lights measured. As a consequence there is no direct relationship between "luminous efficiency," and "candles per

watt." The luminous efficiency and the mechanical equivalent of a source are only rough measures, unsuitable for comparisons.

By taking into consideration the quality of the visible radiation, the idea of "reduced luminous efficiency" has been developed. Here the standard of comparison is the light which, owing to the sensibility of the eye, is the most efficient. By determining the minimum energy necessary to give one spherical candle of this most efficient possible light, a quantity is obtained to which the watts per candle of any illuminant may be referred, thus giving a rational measure of efficiency. This measure of efficiency if expressed in percentage is identical with "reduced luminous efficiency."

What are the useful conclusions to be drawn from this survey?

In order to make a complete discussion of this subject it has been necessary to use a large number of terms, "radiant luminous efficiency," "total luminous efficiency," "the mechanical equivalent of light," "reduced radiant luminous efficiency," "reduced total luminous efficiency." So many similar terms are altogether too confusing to be preserved in use. One conclusion that might well be reached would be that we should cease using the term "luminous efficiency" in its older sense of the ratio of visible to total radiation, using this term to designate the more rational "reduced luminous efficiency." This should certainly be done if possible. It is probable though that the term "luminous efficiency" has been too long attached to the former quantity to offer much hope of its being transferred. The confusion of finding the same term used in different senses would be very undesirable.

In the writer's opinion the best solution of the difficulty is to discard the term "luminous efficiency" altogether. The quantity formerly meant by "luminous efficiency" should be stated explicitly. In place of so many per cent. "luminous efficiency" it is more exact and satisfactory to state that such a percentage of the total energy radiated lies inside or outside the visible spectrum. This is a rough measure of efficiency, and should be so considered. The "mechanical equivalent" of a light can just as well be given without using this name. State that the visible portion of the radiation has such an energy value for unit

light flux. Instead of applying the term "luminous efficiency" to that quantity we have discussed as "reduced luminous efficiency," confine ourselves to "efficiency," meaning lumens per watt. If we wish to compare the efficiencies of two illuminants, compare their lumens per watt, or candles per watt, depending on which unit of flux we have used. If we wish to know how an illuminant stands with respect to the highest possible efficiency, compare its lumens per watt with the lumens per watt of yellow-green light, or if preferred, to that of the most efficient white light. There is no real need for a "luminous efficiency" giving values in percentages. If a percentage value is given it can be stated explicitly that the efficiency of the illuminant is so many per cent. the efficiency of the standard yellow-green or white as preferred. But the writer's belief is that it is best to avoid the use of percentages in this connection. On this view, the figures of the "Lumens per Watt" column of Table IV give all that is usually necessary in the comparison of illuminants. Make direct comparison of candles or lumens per watt, and know the goal of efficiency in light production.

The mechanical equivalent of the most efficient light, with which we make comparisons, is a quantity for future investigation to determine more exactly. The final value will depend upon conventions yet to be decided upon as to the standard conditions of illumination under which we shall consider our standards of intensity to hold their values. In short, it is bound up with the whole question of color photometry. For the present the efficiency of the yellow-green source is so much higher than any practically obtainable efficiency that the existing uncertainty in its value is of no great moment, if we use it as here urged.

DISCUSSION.

C. O. Bond:—In all the figures given, are the degrees on the Centigrade scale?

H. E. Ives:—The temperatures are on the absolute scale or Centigrade + 273 degrees.

C. Hering:—A number of years ago I recalculated the Turmlitz and the Thomsen data, reducing it to modern terms and units. At that time I urged the importance of determining what I then called the mechanical equivalent of light. My suggestion was ridiculed, as some people even doubted the existence of such an equivalent. For this reason I am pleased to see that so able a scientist as Dr. Ives has given this matter so much attention.

E. F. Northrup:—I have several questions to ask. The reduced efficiency of the firefly's light is found to be over 96 per cent. Nature, it seems, has evolved the scheme of producing this light with wave vibrations of such length as to impress human eyes in the most effective way. Has this light been developed so that the eyes of insects are also properly affected?

The firefly's light is perhaps not created to attract human eyes, and it is but natural to assume that the light is used to attract the eyes of the firefly, which therefore must be as sensitive as the human eye to light of the same quality. Probably the eyes of other insects are affected in the most efficient way by these wavelengths, the same as human eyes are affected. We cannot suppose that the firefly would make the most efficient light for the human eye and inefficient light for the eye of an insect.

In comparing different lights of different colors, does Dr. Ives believe that the use of the Flicker photometer is a satisfactory means of arriving at approximately the true light value of different illuminants? This is a debatable subject among people interested in photometry.

How does Dr. Ives arrive at his estimate of temperatures approximating 5,000 degrees: does he exterpolate known temperatures by means of the Stefan law, or by some other radiation law?

Have we any hope of finding a light that is not distributed in the best part of the spectrum, which, by the use of an absorptive

medium, can be reproduced in the most efficient part of the spectrum? By focusing dark rays on platinum, Tyndall raised it to incandescence. He thus obtained light rays from a body originally non-luminous. Can one hope to take a red or a blue light and with efficient conversion change it into a green or orange light?

H. E. Ives:—Replying to the first question asked by Dr. Northrup: It is of extreme interest to know that the maximum sensibility of the human eye corresponds with the wave-length of maximum energy emission of the firefly. I presume Dr. Northrup has also in mind another coincidence that is perhaps explanatory of this coincidence—that the wave-length of maximum energy emission of the sun is also at this point. The human eye has adapted itself to be most affected by the radiation which the sun gives out in greatest quantity, and the position of the maximum of energy emission by the firefly is probably due to a corresponding adaptation. It would indicate that the firefly must perceive colors and light in somewhat the same way that the human eye does.

A question was raised by Lord Raleigh some years ago when Darwin published his first work on "Natural Selection" which is of interest in this connection. Considering the butterfly and other creatures in animal and insect life that mimic the color of their surroundings, Lord Raleigh asked: "How do we know that insects have the same color sense that we have? Do they really mimic?" We may, I think, take the fact of apparent color mimicry and our knowledge of the firefly's light, and consider both as strong evidence for believing the color-seeing apparatus of most animals the same, or essentially the same, as our own.

In regard to the Flicker photometer: I have been studying this instrument preparatory to carrying out some investigations, for which in fact I have the apparatus set up. I find extremely conflicting evidence, from which it is difficult to draw any satisfactory conclusions. Different people get different results, but their conditions of working are rarely the same. All color photometers are dependent upon the size of the field of view, on the illumination, on the state of adaptation of the retina, and perhaps on the way one feels at the time of observation. It is

hard, in brief, to say what does not influence the relative intensity of different colors. Now in order to compare a Flicker photometer with any other, it will be necessary to have all the similar variables maintained constant during both sets of measurements. So far as I know, no complete set of comparisons under such conditions has been carried out.

If Dr. Northrup will look over the results of different observers he will see that they are sometimes different under virtually the same conditions; sometimes alike under different conditions; often alike or different under conditions not completely stated; and the results obtained by some observers cannot be unqualifiedly true if certain results of other observers are.

E. F. Northrup:—The Germans are using a form of Flicker photometer that is a satisfactory instrument for comparing lights of different colors. It is a prism arrangement.

H. E. Ives:—Perhaps the Bechstein form. There are a great many forms of Flicker photometers, but whether the principle itself is correct, or whether it is consistent with itself or with other forms is a question yet unanswered. No sort of theory of its action seems to have been developed as yet.

In regard to black body radiation curves: I simply calculated them from the Wien's equation. As for the transformation of the useless into useful radiation I believe Mr. Hammer in New York has experimented with fluorescent reflectors which, under excitation of the blue and green lines of the mercury arc, give out red light; but as to the efficiency of this transformation I know nothing.

Geo. A. Hoadley:—Dr. Ives has shown us how our methods of illumination differ from those of the firefly. By ordinary methods of illumination we produce a light that is acceptable to the eye, in much the same manner as the voice would produce a satisfactory tone if it should begin at the longest wave-length and strike every one of them until it reaches the proper tone. It other words, in the heat radiations that are given off there is a tremendous loss before the desired light is reached. The problem for the illuminating engineer to solve, then, is to devise some way to get rid of useless radiations; to strike at once the lumin-

ous ray wave-length and thereby attain the economic efficiency of the firefly.

C. Hering:—I am pleased to see that Dr. Ives uses "spherical candles" instead of "lumens" as a correct measure of light flux, thereby getting rid of an additional multiplication: I have drawn the attention of this Society to this matter before.

E. F. Northrup:—Suppose we had a light which exactly imitated the firefly's light. It would then give 100 per cent. efficiency, but our aesthetic sense as to its being the proper color would not be satisfied, as well as white light satisfies it. Would we be approaching the goal if we were to look for an illuminant that is efficient in the same sense that the light of the firefly is efficient?

H. E. Ives:—The question which Dr. Northrup has asked was referred to in my paper published in the October TRANSACTIONS. Certainly the light of the firefly would be unendurable, and infinitely worse than the mercury vapor lamp, but a white light obtained by the same general scheme of suppressing the useless radiations would give a light approaching 20 candles per watt. That would be perfectly satisfactory. It would be white, it would be most efficient, and it would satisfy our aesthetic sense. We do not want to imitate the light of the firefly exactly, but we do want to imitate its light efficiency as nearly as possible, while observing the limitations set by our needs as to color.

L. C. Smth:—What makes the firefly luminous? Also how is its light generated? What is it in the firefly that turns on and off the light?

H. E. Ives:—If I could answer Mr. Smith's questions I should be a multimillionaire, by virtue of the knowledge which I know I should be strongly tempted to use toward that end before imparting it to the world. I am sorry I cannot answer his questions satisfactorily. I can tell Mr. Smith in what class the firefly's radiation falls, however.

We classify radiation as temperature radiation, and as luminescence. Temperature radiation, as the name implies, is produced by the application of high temperature to solid or liquid bodies. We find, however, certain bodies which at a low tem-

perature give an amount of light much greater than could be produced at that temperature by temperature radiations alone. We call these bodies luminescent. The firefly's radiation is luminescent.

E. S. Pelling:—Is the light of the firefly continuous? We see it when the firefly opens its wings. Last summer I noticed a lighted object in a chair; I picked it up and I found it was a firefly, lying on its back.

H. E. Ives:—Ordinarily a firefly in its normal condition flashes intermittently, but as a rule it has a small glow all the time. By the somewhat cruel operation of pressing it between the finger and thumb it will glow more than ordinarily. Ordinarily it has a rather faint glow between flashes. Sometimes when hurt, its light becomes very strong, but that condition seems to use up the vital energy and the firefly becomes exhausted or dies.

F. N. Morton:—I read a number of years ago about an experiment that was made of putting a firefly in an atmosphere of oxygen, when it glowed with increased brilliancy.

H. E. Ives:—Experiments of a chemical nature would indicate that there is some process of slow oxidation that takes place, because, taking away the oxygen, the glow ceases. Of course the insect's life would stop too, but I believe the experiments were carried out in such a way as to show that the luminescence was due to the presence of oxygen. The breathing apparatus of the firefly is such as to supply great quantities of air to the luminescent portion of its body, which would imply that it is some process of oxidation.

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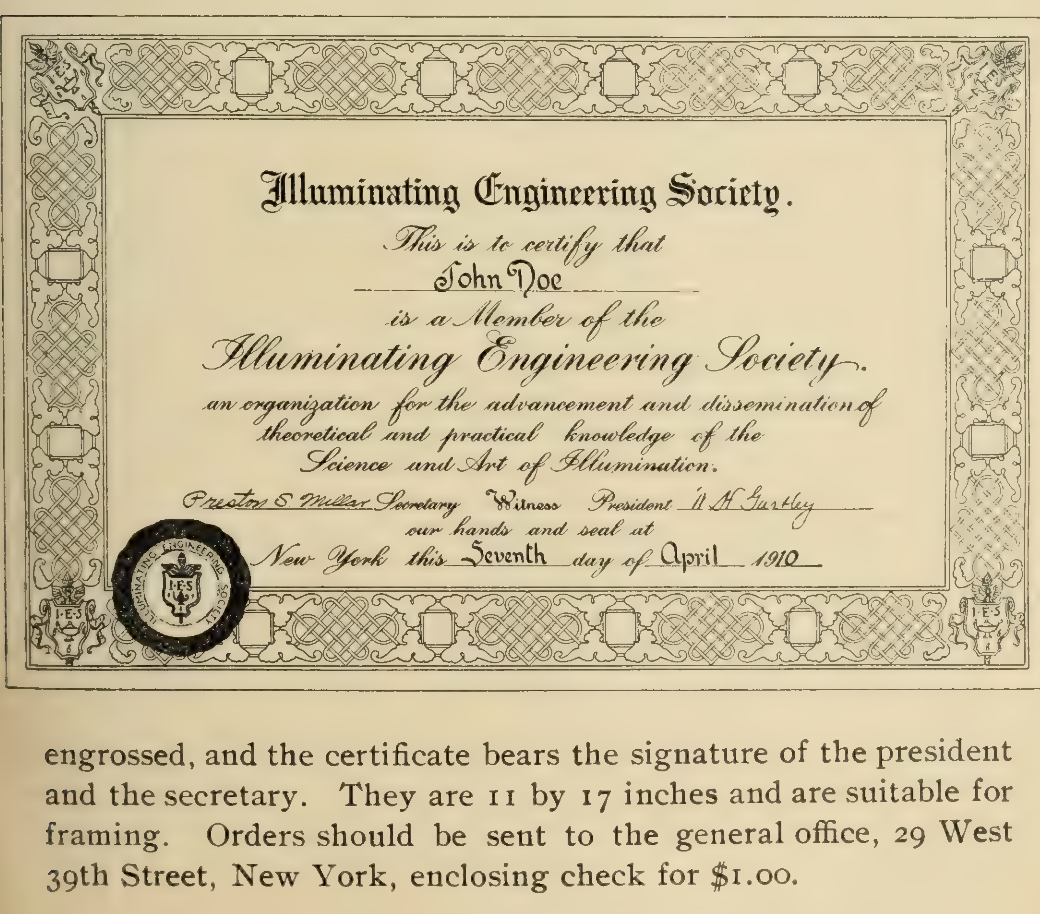

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ILLUMINATING ENGINEERING SOCIETY I·E·S

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The Chicago Section of the Illuminating Engineering Society met in the Grill Room of the Coliseum for dinner at six o'clock Thursday evening, January 20, 1910. The subject of the evening was "Indirect Lighting." Chairman Scheible, presided.

Chairman Scheible:—At one of our previous meetings we saw the first public introduction of a practical method of indirect lighting suitable for residences, which was then in an early stage of development. Since that time it has been introduced to a considerable extent, and we have had opportunities to observe its practicability.

There is an important practical phase of our topic; namely, the cost of maintenance of such indirect systems in comparison with methods heretofore used. Perhaps no one among us has had quite as much experience along these lines as Mr. Pearson of Marshall Field and Company.

E. J. Pearson:—It is manifest that a comparative cost of maintenance must include, first, cleaning of glassware and fixtures; second, renewals of glassware and repairs on fixtures; third, renewals of lighting units. The first and second costs may be stated in a more or less general way, but the third item must in each case depend entirely upon the type of unit under consideration, that is, whether it is upon tungsten or carbon filament units, Nernst or arc lamps. For this reason I am compelled to omit facts on this latter item of cost which should be determined and applied in each individual case.

It is further evident that the cost of maintenance per kilowatt-hour will be greater or less, depending upon the monthly consumption of current per candle-power of units installed. It is also obvious that the cost of cleaning will be influenced by the nature of the business, the location of the building; also the geographical location, will all have more or less influence upon the cost of the cleaning per unit of current consumed, as illustrated by the fact that lamps and fixtures in a residence would not have to be cleaned as often as fixtures in a planing mill or foundry. Furthermore, apparatus in use in a small residence city would not accumulate dust and dirt as quickly as an installation in a smoky, dusty, manufacturing locality. All of these items must have consideration in any attempt to determine the

relative proportion and cost of maintenance of any indirect or direct system of illumination.

The following are a few of the costs which I have been able to get together in the short space of time at my disposal:

Library Building, cost of cleaning and renewals three mills per kilowatt-hour. Residences, cost of cleaning and renewals, five mills per kilowatt-hour. Theatres, cost of cleaning and renewals, three mills per kilowatt-hour. Churches, eight to fifteen mills per kilowatt-hour. Factories four to six mills per kilowatt-hour.

In the above cases the library building maintenance is taken care of by the regular janitor, the churches by the janitor, the residences by the maids, factories and stores by the electrical repair crew, and theatres by regular house employes.

In large merchandizing establishments, it would appear to me, as far as I have been able to ascertain, that the cost of this cleaning carried on systematically by regular janitor service could be reduced to approximately one mill per kilowatt-hour, estimating the cost of cleaning on the basis of labor at $1.50 per day per man, cleaning once each month. This is purely a hypothetical estimate. I have no data which would accurately confirm this figure.

Take the case of the illumination of theatres by means of indirect light that is generally done by means other than the inverted bowl or reflector. It has been accomplished heretofore by troughs around the room or in the arch ways, and an application of whitewash upon the reflecting surface. But the cleaning is a factor that has been entirely neglected. I don't suppose some of the cases I have noted have been cleaned twice a year. The cost of maintenance in such case is undoubtedly low, but the result is very poor efficiency.

Henry Gradle, M.D.:—The difference between indirect and direct illumination which appeals particularly to the oculist is that the former resembles daylight illumination more closely. As in daylight, the shadows are not so pronounced. The illumination is not so intense in any one small area, and in general is much more uniform. In any direct system of illumination we deal with a small area of great brilliancy, if it is at all

efficient. It is known that all organs work to best advantage under the conditions under which they have been developed in the course of ages, and the eye has been developed under daylight illumination. It is scarcely more than a few generations since we have had artificial illumination of any real intensity. We can, therefore, say in a general way that we would expect the eye to be least taxed under normal daylight conditions. This is borne out by experience. I do not know of any accurate tests comparing the indirect with the direct form of illumination, but we all do know that there is a vast difference in the tax upon the eye on comparing natural illumination with the artificial. In the case of the normal eye not over-taxed by work, the difference is not usually appreciated at the time, but I must add that in a large number of persons the eye is not perfectly normal. Proper glasses could in many instances improve, but they are not always worn. A large number of people are unfortunate in having sensitive eyes for other reasons, and such patients usually find that they can work to better advantage in daylight than under ordinary systems of direct artificial illumination. The experience of the oculist has been that the nearer we approach the natural lighting the less the tax upon the eye.

In comparing the direct with the indirect systems we must assume of course that either is of sufficient intensity for practical purposes in order not to tax the eye unnecessarily. There are two physiological peculiarities which are not sufficiently appreciated, but which bear upon this subject. The first of these is the adaptation of the organ of sight to the surrounding illumination. We all know that when we pass from daylight into a dimly lighted space we cannot recognize details. If we analyze this phenomenon, we will find that the eye exposed to a high illumination is not so sensitive to small differences of illumination as it is after having become adapted to darkness. In fact, the difference between the eye adapted to daylight and the eye adapted to a low degree of illumination is enormous. The difference is not expressed by a small fraction, but by multiples running up into the thousands. The eye accustomed to the brilliant illumination at mid-day is not adapted to and is at a great disadvantage for a time upon entering a dark space. Pretty soon,

however, the eye accustoms itself to the surroundings and can readily distinguish objects that at first were not recognizable.

The eye adapted to a low degree of illumination is also at a disadvantage when the general illumination is raised, as on leaving a dimly lighted space and entering the open air. It is not the want of sensitiveness of the eye in this case, but it is the dazzling from which it suffers under these conditions. It takes an appreciable length of time for the eye to adapt itself to the surroundings. We will find that during the first few moments the adaptation of the eye to darkness increases at a very rapid rate, then at a slower rate, until from 45 minutes to 1 hour the full adaptation has taken place.

An illustration of working when the eye is not fully adapted is seen when we try to light up a room during the twilight hours with artificial illumination without pulling down the shades. Lamps which are satisfactory later on are inadequate while the eye is still under the influence of waning daylight. This question of the adaptation of the eye to varying degrees of illumination is the first point to consider.

The second point is the check which the illumination of a small area of the retina exercises upon the sensibility of the entire eye. A very striking way to observe this is to leave the house when it is difficult to recognize objects out of doors in the evening while carrying a lantern. The lantern held directly in front is a distinct detriment to vision. The lantern casts apparently a physiological, not a physical, shadow upon the objects at which we gaze, and it is a distinct check upon the vision.

What is the application of these two principles in the case of indirect and direct illumination? In direct illumination we have a concentrated single light, or multiple lights as the case may be, showing that within the range of vision the eye does not ordinarily remain fixed continuously upon the paper which we may be reading but wanders at times in different directions. The surrounding objects are all of a feeble degree of brightness as compared with the source of light. Hence, in this case the adaptation of the retina varies as the eye is alternately directed at areas of widely different brightness, and in consequence the eye is not used under the most economical conditions, physiologi-

cally speaking. Besides, there is a distinct check put upon its analyzing power every time an image of the source of light falls upon the retina. The consequence is fatigue. The more nearly an indirect illumination approaches the uniformity of daylight surroundings the less this fatigue.

Geo. H. Jones:—I have no figures on the efficiency of the eye under direct and diffused lighting conditions, but I have tried this system in my office and in my home for over a year, and will be glad to give my experience with it.

During the last year or so, we have placed too much emphasis on the matter of giving proper illumination simply on the working plane. In such working spaces as private rooms, offices, not used by the general public, shops, etc., it is proper to install lighting units in such a manner that most of the light is directed to the working plane, and so secure results with a minimum expenditure of energy. In cases, however, where rooms are to be used by the general public, and stores, homes, etc., it is necessary for proper effects not only sufficiently to illuminate the working plane, but in addition the entire space must be lighted sufficiently to make the room cheerful and attractive.

In talking over the matter with merchants you find they wish their entire store lighted. In going from one extreme, however, we should avoid going into the other, and should try to reach a happy medium. In my opinion a system of indirect lighting when combined with certain portions of well-shaded direct lighting is ideal for many classes of work, especially in those cases where the illumination is desired only for use at night. The use of localized lighting, especially when the units are housed in ornamental stand lamps or wall brackets with light-colored art glass shades certainly gives pleasing and attractive results. In cases where the indirect lighting is used in rooms having dark colored walls, the light is all thrown from the ceiling in a downward direction which gives unpleasant shadows under the eye. This is counteracted by localized lighting.

In one room of my home I am using about one-half watt per square foot (tungsten lamp) in indirect lighting, and also using an ornamental table lamp with amber-colored art glass shade.

The walls of the room are dark brown and the ceilings a very light brown to harmonize. The lighting effect is very pleasing and is exceedingly restful to the eye.

I find that indirect illumination in this case, while ample at night, is entirely inadequate at twilight, so that without the stand lamp, especially for these hours, the room could not be used without materially increasing the amount of direct illumination. If the indirect illumination were increased sufficiently to take care of the twilight hours, it would be altogether too strong for the evening hours. This would be undesirable, as too intense indirect illumination is, in my opinion, trying on the eyes.

In my office both the walls and ceilings are painted a light cream color. I use about one watt per square foot (tungsten lamps) of indirect illumination. It gives a cheerful appearance to the room. I found, however, that the illumination was rather tiring on the eyes to work by, so it was necessary to add localized lights in the form of desk lamps.

One point that might be brought up is the effect of fresh paint. Of course, it is expected that a light colored paint will give much better effect than a dark color. It is surprising, however, to find that fresh paint, although about the same color as the old paint, wonderfully improves the illumination.

One other feature which seems to me important. If you have a room properly lighted up with combination of direct and indirect lighting so that the results are satisfactory, it is essential that no brilliant lighting units be used in adjacent rooms. If such units are used the effect on the eye in passing from one room to the other is distressing.

J. R. Cravath:—There are many installations of this kind in Chicago, probably the most notable is at the South Shore Country Club, where the installation of tungsten lamps on the basis of about one watt per square foot has given a result that leaves nothing to be desired.

One point brought out by both Dr. Gradle and Mr. Jones, should be emphasized, that is, the necessity of providing more light for twilight conditions than we provide for hours when full darkness prevails. We look at the open space of the window, which is brightly lighted, and then down at the paper, and

unless the paper is illuminated to somewhere near the same degree it will not be satisfactory. I think it would be safe to say that one should provide nearly double the illumination where there is a mixture of daylight and artificial illumination than in places where no daylight is received whatever.

In regard to the desirability, in some cases, of combining direct and indirect systems. There are many cases where that is desirable. I believe, however, that the direct light in such cases should be almost completely shaded either by dense art glass or something similar. In direct light of this kind one should be careful to get the light from an angle so as not to get the glare from it. The glare from paper is one of the hardest things we have to contend with.

As a general thing it seems to me that sufficient indirect light for working purposes in offices, etc., is better than trying to supplement the light with the direct system, except where very high intensity is needed at some particular point. In other words, where you have a little direct light, supplementing your indirect, it must be arranged in such a position that you do not get the glare from the paper.

I had a case come up within the past week where indirect light was being used in conjunction with direct in an office, and it was brought to my mind very forcibly not to have too much direct light supplementing the indirect. Most of the people working under the indirect system had no direct light. A few people in the office had individual desk light. Some of the people under the indirect lighting were dissatisfied, claiming that the lighting was insufficient for their purposes. There was really nothing to these objections. The illumination was excellent. The trouble was simply the contrast between the intensity under individual lamps and the intensity in other places. This led those not having individual lamps to think they did not have sufficient illumination.

Regarding the maintenance part of the proposition, comparing the direct with the indirect systems. It is not necessarily any greater with indirect than with direct. In fact, it may be less, but if I considered the two systems, I would consider them on the basis of cleaning about the same number of times per year in

each case. The matter of cleaning the ceiling, as Mr. Pearson has said, is a matter that is taken care of in large institutions, and you would not have to consider that point. In direct lighting the glassware has to be cleaned. One would not necessarily have to spend more time on the indirect system. There is one danger in the indirect system: the glassware is out of sight and is apt to be forgotten.

It might be of interest at this time to give you a little summary of tests that have been made in the past four years on indirect lighting.

The first test is the one that was reported in Mr. Preston S. Millar's paper.[1] The test was made in a room 16 by 11 ft. by 12.5 ft. high, with white walls and ceiling. No reflectors were used under the lamps. The watts per lumen with carbon filament lamps were 4.1, and the equivalent watts per lumen with tungsten lamps 1.68.

Another test was made in the library of the Boston Edison Company's building. It is a large room with light walls and ceiling, with a special curvature of the ceiling to get efficiency. The method employed was the cove lighting system, and the lamps used were the O'Brien tubular. The watts per lumen were 0.95, and the estimated equivalent watts per lumen for tungstens about 0.355. The test was made by Dr. Louis Bell.[2]

The third test was in the Auditorium of the New York Edison Company's building. It is a very large room, and the cove lighting system was employed. The room had a curved ceiling, and the cove was enameled white before the test was made. The watts per lumen with carbon lamps was 1.25. The equivalent watts per lumen for tungsten lamps 0.525. The test was made by Messrs. Sharp and Millar for the Association of Edison Illuminating Companies.

The fourth test was made in the Harlem Office of the New York Edison Company, in a room 51 by 23 ft. by 23 ft. high. The room had white walls and ceiling, and the cove lighting scheme was employed. The room also had a curved ceiling. The watts secured per lumen with carbon lamps 4. The equivalent watts per lumen for tungstens 1.68.

[1] Transactions I. E. S., 1907, p. 583.
[2] Transactions I. E. S., 1907, p. 623.

Another test was made by Professors Snow and Freeman of Armour Institute of Technology, and reported by myself,[1] was in a room 12.66 by 12.75 ft. by 9 ft. 9 in. high. The ceiling and walls were light in color. The "eye comfort" system was employed. The watts lumen secured were 0.35.

In still another test of the "eye comfort" system made by Professors Snow and Freeman, and reported by myself,[2] was in a room 15 ft. by 15.16 ft. by 9 ft. 9 in. high. The ceiling was a light cream and the walls a dark green. Watts per lumen were 0.45.

In a recent test, made by Mr. R. B. Ely, of Philadelphia, the room was 15 ft. 7 in. by 20 ft. 9 in., and contained 308 square feet. Space being taken out of one corner. The height was 9 ft. 9 in. with a light buff ceiling and light buff walls. The watts secured per lumen were 0.325.

E. L. Eustis:—I should like to give a few of the figures I have on tests that I have made on such indirect lighting. In the first installation the ceiling was tinted a light yellow, the walls a light yellow, floor light in color, furniture dark oak, with the bays 7 ft. 3 in. by 13 ft., area of 94 sq. ft. The room was 26 ft. 4 in. with a ceiling 9 ft. 11 in. high, with the light 2 ft. 6 in. from the ceiling, using 100-watt bowl frosted tungsten 110 volts, watts per sq. ft. 1.065, mean illumination 1.67, lumens per watt 1.57, watts per lumen 0.638.

In the second installation the ceiling was white, the walls half white and half yellow, the floor red, the furniture oak, the bays 16 ft. 2 in. by 25 ft., area 404 sq. ft. This was a rather large room 17 ft. 9 in. ceiling, using four 100-watt bowl frosted tungstens, 110 volts. The watts per square foot were 0.992, mean illumination 1.94, lumens per watt 1.95. Watts per lumen 0.51.

In the third installation the ceiling was light yellow with a striped design of silver paper, the walls upper half light green and the lower half dark green, with a dark red carpet, the furniture was light color, bay 18 ft. 3 in. by 42 ft. 9 in., 782 sq. ft., the room was a rather large one, and the ceiling was 14 ft. high. Lamp to ceiling 3 ft. 6 in. Two three-light 100 watt bowl tungsten fixtures were used, 110 volts. Watts per square foot 0.767, mean illumination 0.95, lumens per watt 1.235, watts

[1] TRANSACTIONS I. E. S., 1909, p. 290.

[2] TRANSACTIONS I. E. S., 1909, p. 290.

per lumen 0.807. The fixtures were very dirty, and probably had not been cleaned in several weeks. The percentage of illumination gained by cleaning was 21.

In the fourth installation the ceiling was light yellow paper with a silver design, the upper half of the walls were light green and the lower half dark green, with a red carpet. The furniture was light colored. Bays 18 ft. by 42 ft. 9 in., 782 sq. ft. The room was rather large, ceiling 14 ft. high, lamp to ceiling 3 ft. 6 in., employing two three-light bowl frosted tungstens, 110 volts. The installation was clean. Watts per square foot 0.767. Mean illumination 1.15, lumens per watt 1.50, watts per lumen 0.667.

In the fifth installation the ceiling was light blue-green. The walls medium green, the floor dark, the furniture oak, bay 20 ft. 6 in. by 90. Lamps to ceiling 16 ft. 10 in. using two 3-light 100-watt tungsten fixtures, 110 volts. Watts per square foot 2.61, mean illumination 2.173, lumens per watt 1.20, watts per lumen 0.825.

In the sixth installation the ceiling was white the walls green, the floor light, furniture dark, bay 17 ft. by 19 ft. 5 in., sq. ft. 332. Medium sized room, lamps to ceiling 18 in., using two 150 watt and two 100 watt clear tungstens in series, voltage 110. The watts per square foot were 1.505, mean illumination 1.99. Lumens per watt 1.325, watts per lumen 0.757, with the glassware dirty. In the same installation with the glassware clean the mean illumination was 3.69. Lumens per watt 2.45, watts per lumen 0.408.

In the last installation the inverted arc system was employed. The ceiling was a yellowish white, with light yellow walls, light colored floor, and dark furniture. The ceiling was 14 ft. high. Lamp to ceiling 20 in., using one arc, 110 volts. Watts per square foot 3.76 mean illumination 6.06, lumens per watt 1.61, watts per lumen 0.621.

L. B. Spinney:—I fully agree that our visual organs operate to the best advantage and with the most comfort when they are used under conditions which approximate as nearly as possible those found in nature, and I believe that this should be taken as an indication that we should study the natural conditions of illumination. I must, however, disagree with Doctor Gradle, if

I understood him correctly, in his discussion of certain features of the illumination found in nature. I wish to ask you to consider the conditions on a day when the landscape is illuminated by a bright sunlight. A large amount of the illumination under such circumstances comes directly from the sun, and a smaller amount is diffused from the sky. This will be evident from the fact that all objects cast shadows, and even small objects when they are near the ground, which in this case, is the reference plane, have fairly well defined shadows. We have thus, under these conditions, a large amount of diffused illumination, but in conjunction with that is a quantity of direct illumination sufficient to cast a fairly dense shadow. It seems to me, therefore, that a study of these natural conditions of illumination would indicate that the proper kind of illumination is that which combines the direct with the indirect, having a sufficient amount of direct illumination to cast shadows, thereby showing bodies in their proper proportion, size, and shape.

Every one recognizes the great difference between the illumination of the landscape on a bright, sunny day, and on a cloudy day. The illumination on a cloudy day is dull, uninteresting and even depressing. There is no contrast and the appearance of the landscape is what the photographer calls "flat." When the sun comes out from behind the clouds the shadows appear, and our interest in the landscape at once increases. This effect should be taken into careful consideration in designing a system of artificial illumination for an interior. It is desirable that the room be cheerful, and interesting in its illumination, and any system which does away in a large measure with shadows, is one which is not designed to secure these effects.

Every one recognizes the cheerlessness of an illumination which is absolutely uniform. A room flooded with light, which gives uniform illumination, appeals to one as cold and comfortless. I feel, therefore, that judged from the standpoint of our present knowledge, that illumination would be most successful which combines the direct and indirect systems. Of course a system of this kind would necessitate the adjustment of the direct illumination so as to do away, as far as possible, with sources of high intrinsic brilliancy, thereby overcoming one of the most serious objections to that kind of illumination.

A paper presented at a meeting of the New York Section of the Illuminating Engineering Society, New York, January 13, 1910.

SELLING ELECTRIC LIGHT.

BY T. I. JONES.

It is the purpose of this paper to present in a general way some facts with regard to the sale of electricity for illuminating purposes; to outline some of the conditions which must be met in such service; to discuss various forms of contracts under which current for light is sold; and finally to consider the matter of sales department organization.

The Commodity.—In discussing the selling of electric light, there must of necessity be included the consideration of the sale of current for other than strictly lighting purposes—such as heat and power—and in the general discussion of the forms of contracts used and the analysis of the organization plans, this fact must be borne in mind.

In selling electric light, the investment in the plant is the most important item; that is, the amount of money the company must expend in order to be in constant readiness to serve customers up to their full capacity. The equipment which the company must install not only in generating power, but in mains, extensions, services, material and labor, to be ever ready to serve all its customers if necessary at any one time to their maximum load—what we call the readiness to serve expense—this is the condition imposed on every electric light company to which I would call attention.

Suppose for example that the proprietor of a dance hall contracts with the sales department of an electric light company for services to his hall, which he may use intermittently two or three times a week for five or six hours at a time. To supply this man the company must place at once an equipment, not only in its generating stations, but in its mains running to the substation feeding this locality and in distributors from the substation, a capacity sufficient for the complete current requirements of the hall. While this equipment could be used twenty-four hours per day seven days in the week, it actually is used

only a small part of such a period. It is the "idle use" of such an equipment, (if I may use such a term), which must be considered in determining the rate of the party served.

Take another case, a tenant in a residence or an apartment signs a contract for electric lighting service. He contracts for an equipment, say of twenty or thirty lamps. He uses three or four lamps at the most for an average of three or four hours per night. The house may be closed three or four months in the year, yet the lighting company is asked to install an equipment sufficient to light the complete installation with all the lamps burning.

It will be seen at once from these two examples that the period of use of the consumer's equipment—or what is called the load-factor—is really the governing point to the central station.

Fig. 1 illustrates the output of a central station—as a matter

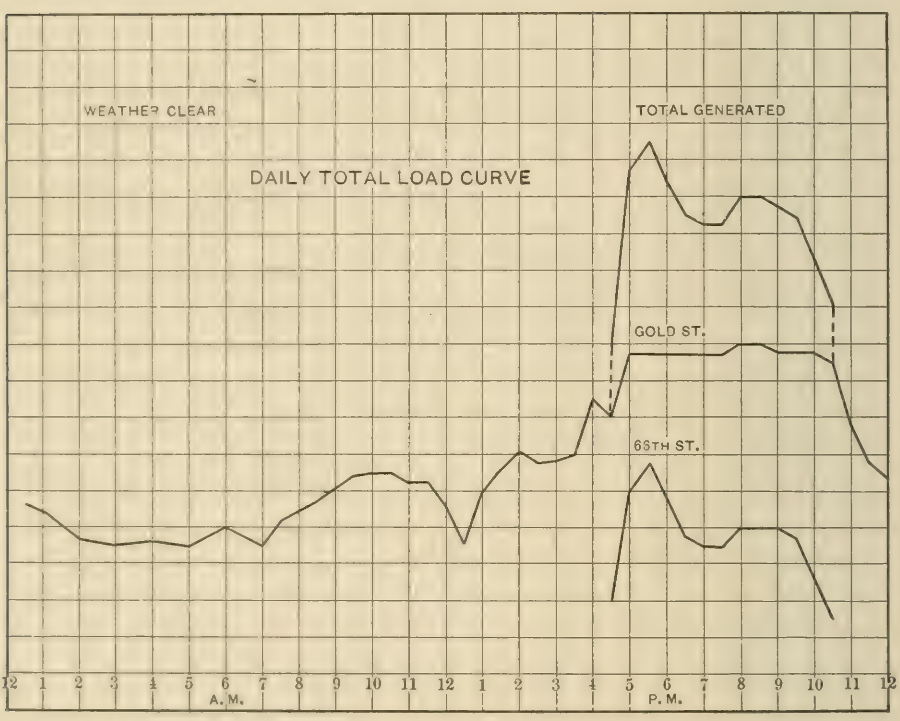

Fig. 1.

of fact this is a real curve showing the output of two generating stations of one large plant. It will be seen from these curves that between the hours of 5 and 8 p. m. the plant reaches its maximum capacity, while outside of these hours the load very

materially decreases. Though additional generating machines are used to take care of the increased demand on the system, all the generating machinery required for this peak load—all of the mains and subsidiaries necessary to supply the customers at any time if necessary—must be maintained throughout the entire 24-hour period. In short, the company's mains must have sufficient reserve force, if called upon, to supply the entire equipment for an indefinite period, even though as a matter of fact the entire equipment be actually in service less than 4 hours during the day.

The special point which Fig. 1 brings out is that the whole of a large generating station is required between certain hours during a few months of the year to carrry this peak; that the rest of the 24 hours of the day during the year this plant remains idle with no return on the investment charges; that this investment is necessarily paid for by the customer; and that the fairest way and most logical way to cover it is by charging the customer an amount proportional to his installation together with a fair rate for the amount of current used.

These facts are mentioned early in the paper so as to enable you to appreciate what I shall have to say later in discussing rates. Then you will appreciate what is meant by the statement that a man who consistently uses his service 7 or 8 hours during the 24 should properly pay less per unit for such service than he who simply uses current 1 or 2 hours—and that possibly on the peak.

It must appear to you at once that if the company could adopt any policy or so adjust its rates that this peak would be level, and a uniform output could be maintained throughout the night, so that all the machinery could be kept working steadily and not concentrated during any one period, then the cost of producing the current would necessarily be lowered and the rate to the consumer correspondingly reduced.

Fig. 2 shows graphically the relation of the cost per kilowatt-hour to the load or kilowatt-hour output of a generating station. This curve is plotted hourly and shows the reduction in cost produced by a distribution of the load. If it were possible to carry continuously the load that is shown from 5 p. m. till 9.30

p. m., during the rest of the 24 hours, the reduction in cost to the customer would be considerable. Under a load-factor rate based on a readiness-to-serve charge, this is actually what is done. The individual amount of current used by the long-hour customer raises the load curve during the low-hours and consequently

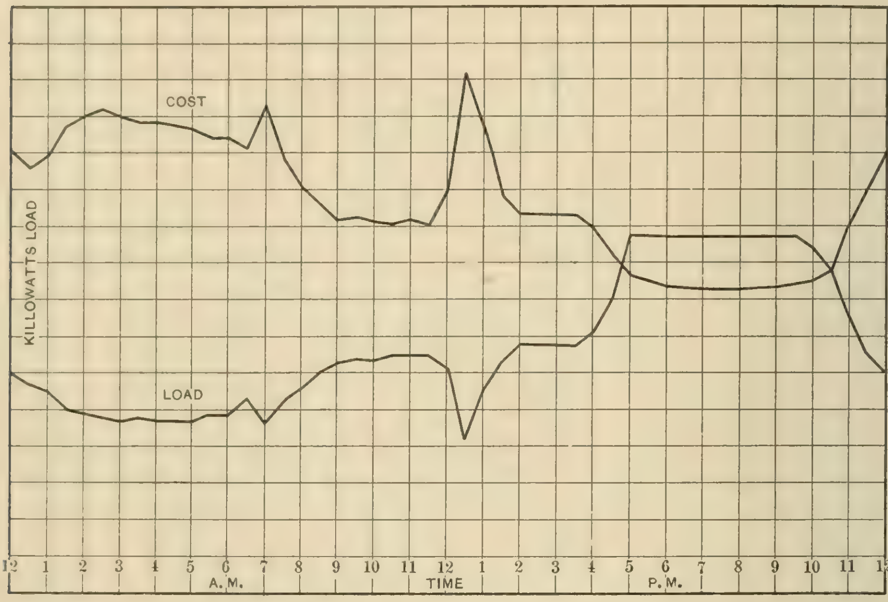

Fig. 2.

lowers the cost curve during those same hours. The customer should receive and does receive, under this form of contract, the benefit which the company receives from his long hour use.

Equipment Expense.—So much for the question of load factor. Another item having a direct bearing on the cost of supplying current, particularly to the small user, is the equipment expense which the company must incur in its readiness to serve all installations at the full capacity at any one time, namely: meters, switches, lamps, etc.

Take the case of the small apartment where with the advent of the high efficiency lamp and the reduced rate for electric service, the increased demand has been remarkable. Say there is an apartment where the installation is from ten to fifteen lamps, often not more than five or six. Such an installation would require the installment of a meter costing from $10.00 to $15.00, to say nothing of lamps, switches, service, etc. Now assume the use of that equipment is less than 1 hour per day throughout the

month. The revenue from such an apartment at 12 cents per kilowatt-hour would be less than $1.00 per month. It does not require a mathematician to appreciate the length of time this apartment must use current on this investment before the lighting company receives any kind of a return on its equipment expense to say nothing of profit.

The equity of a minimum charge for such class of service, therefore, becomes immediately apparent. It is precisely analogous to the telephone contract with a minimum of 600 messages per year. The charge is for 600 messages whether one or 600 is used, and all additional messages are charged for at a reduced rate. The price per message of the first 600 calls does not mean that each message costs so much for the operating expense alone, but that the telephone user is paying a certain amount to the telephone company for the investment in its instrument and wire; and this investment is represented together with a small charge for the message, in the minimum rate charged.

Having in mind both the load factor and the equipment cost for large and small users respectively, I present for your consideration the equity of a rate made up of two parts, one a standby charge or payment to the lighting company for the investment it must make to supply the equipment necessary for the consumer's demand; and, second, a current charge for the actual amount of electricity used by the consumer for the equipment installed. I would ask you to keep the necessity of these two charges in mind while considering the various classes of rate which will be taken up as existing at the present time.

There is a regular maximum demand type of contract in which the readiness-to-serve or standby charge is arrived at in two ways, partly by specifying a certain rate per killowatt-hour for a certain number of hours monthly use of the maximum demand, and partly by a sliding discount on that part of the bill figured at the lowest kilowatt-hour charge. As one means of determining the maximum demand certain percentage figures are used for installations of various sizes for establishing this demand. These percentage figures are obtained by averaging the results obtained from many thousands of customers and in practice work out so closely as to be satisfactory. Another means of de-

termining the maximum demand is through the use of demand recording meters or indicators.

Special Forms of Contracts.—What has been said up to this time relates to the regular service of small and large consumers in the general run of interior illumination for premises wired. In the procurement of this business—with all justice to ourselves—we must acknowledge that we cannot help but get a large part of it: for the average up-to-date merchant in opening a new store opens it with the idea fixed in his mind that he will light is electrically and it is wired accordingly. Occasionally he goes to the electric lighting company without any soliciting on its part. Often this is the case with the up-to-date residence or apartment. A great amount of this business comes without solicitation by the lighting company and does not require serious consideration in sales department methods in this paper.

There are, however, two particular types of customer which must be solicited actively. One is the customer who wants to use a great amount of light and power, and who is considering the installation of a plant; the other is the small user who can be supplied from the company's system but hesitates to go to a wiring expense for such service.

The first class is taken care of by a properly organized power branch of the sales department. The second class requires a means of approaching the customer with a plan for installment wiring and active soliciting on the part of the agent concerned. I have in mind particularly the small store, say a barber shop, lighted by oil or gas. It is not wired. For this class of customer, we have in Brooklyn a special company run as a branch of the sales department. This company is known as the "Tungsten Lamp Specialty Company." It secures its business through a contract that permits the customer to pay for his wiring and lamps in monthly installments. This contract has worked out very satisfactorily in Brooklyn. In the twenty months the company has been operating, contracts have been closed with nearly 2,000 customers (formerly using by gas and oil) with a total of 20,400 50-watt equivalents.

Another class of customer is the advertiser who desires to use a certain amount of current for sign or display work, but must

know each month how much to allow for such display. For such purposes we have drawn up an advertising contract. This is merely a flat rate contract charging so much per month, the company turning the sign on at dusk and off at midnight.

City Lighting.—What has been said before relates principally to commercial lighting. Contracts with the city for street illumination are generally made under specifications drawn up by the chief engineer of light and power of the municipality, the types of lamps being specified in wattage consumption and the hours indicated according to a prearranged chart determined from almanac.

Sales Department Organization.—In many cities the gas and electric interests are consolidated. As a consideration of such a combination would involve much explanation, I will eliminate that type of company and confine my statement to the sales department organization of companies devoted to the sale of electricity exclusively.

The general form of organization at present in service by the sales department of the Brooklyn Edison Company is that shown in Fig. 3. Under this form of organization the territory is

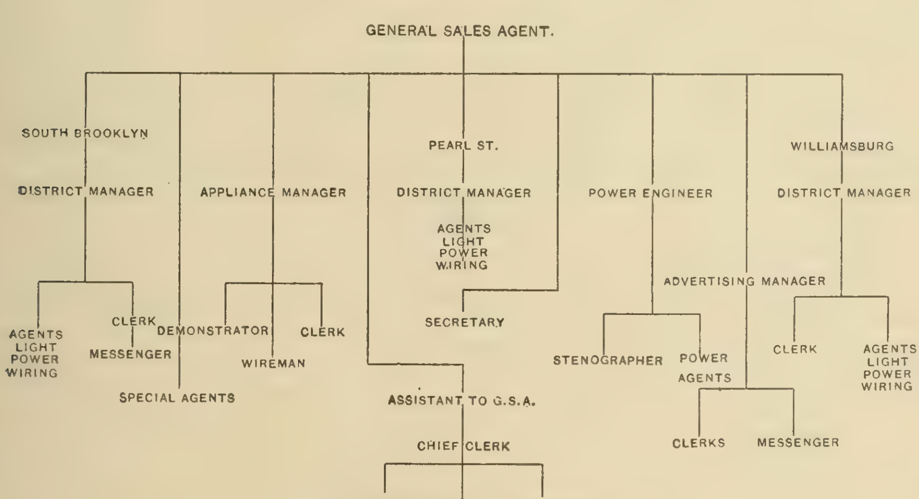

Fig. 3.

divided into districts which come under the direct charge of the district manager who reports to the general sales agent. Under each district manager are three classes of agents; one class devoting special attention to lighting, a second to power, and the

third to substitute electric for non-electric illuminants. The latter class of agent is included in the word "wiring" on Fig. 3. A clerk and a messenger are also provided to handle the clerical end of the district work. All contracts for business originating in the districts are forwarded to the chief clerk of the sales department at the main office. There the necessary orders are made out, contracts checked, and the action of the department as a whole kept in such shape as to be readily overseen by the general sales agent.

At the main office there is also maintained a staff of specialists. For handling the large contracts in power a power engineer with assistants is available. He also acts in an advisory capacity to the power agents under the district managers.

An appliance manager is in charge of a department covering all electrical household appliances including heating apparatus, decorative lighting, portable lamps, etc. A large showroom is maintained at the general office, and ample displays are also shown at the branches.

All company advertising is handled by an advertising manager and his staff under the direct supervision of the general sales agent.

Special agents covering advertising and large sign lighting, government work, city lighting, and the following-up of new buildings, and the keeping in touch with architects, are also provided, coming directly under the general sales agent.

This form of organization is flexible, allowing any special installation to be readily handled without interferring with the regular routine, and can be indefinitely enlarged without requiring any change other than the establishment of more branches.

Work Reports.—The connection between an agent's work and the departments effected by his canvass is in a form known as the "Agents' Inspection Report." This report is made daily by each agent and forms the basis of the work order which goes direct to the construction departments concerned. This places the responsibility of all work directly upon the agent who takes a given contract and holds the agent responsible for all the details necessary for the complete and satisfactory execution of the order.

As aids to the agent and in order properly to classify all requests for agents to call and inquiries regarding cost of lighting, power, and etc., lead memorandum sheets are used in connection with an agents book. These sheets are made out in duplicate at the main office of the sales department and are forwarded to the district manager or special agent concerned. The leads require a report from the agent as to the disposition of the inquiry.

The Red Book.—As a further aid in order to instill a spirit of co-operation between all departments of the company, what we know as "The Little Red Book," is distributed generally to all employees of the company. This red book is simply a medium for each employee of the company to call the attention of the sales department to any possible opportunities for new business, or to bring to the attention of other departments complaints of defective service or matters in which the general welfare of the company is concerned. The red book memoranda are recorded and made the basis of a lead sheet to the agents. At the end of each year the red book leads are carefully totalized and a suitable recognition made to the employee of the company turning in the greatest number of satisfactory sheets. In this way the entire force of the company is made really a part of the sales department and a spirit of general co-operation, for the company's welfare instilled in all.

Special Advertising.—In order to create interest by the public in general and among our existing customers and new customers, our advertising department continually sends out literature of various forms—street car advertising, newspaper advertising, theatre-program advertising, leaflets in the mail, etc.—all of which are used as means of directing interest in the commodity we have to sell.

Occasionally special pamphlets to reach a given class of customer are sent out. Such as Yiddish and Chinese circulars.

Personnel of the Force.—I have been asked many times the requirements of an electric light and power salesman. This is a matter always entirely of personal equation. The better educated a man may be, as a general rule, the better fitted he is to go to the better class of customer; but it is my earnest belief that salesmen are born, and not made, and that every success-

ful salesman is successful because he has had the spark of salemanship developed, but the spark is there nevertheless. No amount of training could bring out in a man the ability to sell if the nucleus of that ability were not in his makeup. In the power solicitor, of course, technical knowledge is essential; but the best engineer in the world might be an absolute failure as a solicitor if commercial ability did not exist within him.

If it were possible to obtain well-educated young men trained in the electrical and mechanical engineering departments of our best technical schools, who possess that selling ability which results in the closing of contracts, that type of man would be what we all desire. Approaching our ideal we seek that type of man, necessarily of good address and of good education, who has within him exceptional selling ability to a material degree.

It is realized that with the space of time given to discuss the subject before you only generalities can be touched upon. The subject of selling electricity either for light or power is so intensely interesting that one might devote a series of lectures to it without exhausting the topic. If, however, the points brought out in this talk have interested you for one hour and a half, and if they will be the means of causing you to think along the lines indicated, the object in writing the paper has been accomplished.

DISCUSSION.

J. D. Israel:—Reference has been made to salesmanship. Now salesmanship has been well defined as the selling of goods at a profit with satisfaction to the customer. The lighting salesman must satisfy the consumer and must present his proposition to the customer in such form that he will be convinced that he is being served on an equitable basis.

The president of the Illuminating Engineering Society, at a recent meeting, stated that the object of the Society is to get the science and art of illumination working together; the application of the scientific principles working harmoniously with the practical problems of the commercial man.

In Philadelphia the schedules of discounts and rates are based upon the average hours use per unit per day. The consumer who has a large motor installation with the same average hours use as a small installation, is entitled to a greater discount because of the quantity factor. The large installations paying greater amounts of money usually carry the use beyond the peak.

There is a minimum charge to cover certain expenses incidental to readiness to serve and maintenance costs. When it is necessary to make a long extension beyond the regular lines of the mains, we give the prospective customer service on a basis of a certain charge for such extension together with a guaranteed minimum to the company in order to compensate the company in an equitable manner for such special expense and maintenance as will be required to serve the consumer.

The Philadelphia Electric Company has been conducting for a number of years a show room which is believed to be the equal of any in the country as to general appearance and location. This show room is in the central business section of the city. There are other show rooms at a number of the Company's district offices. The district manager is the company's representative in each district, and he possesses a certain combination of engineering and commercial knowledge and training. The solicitors of each district are under the direction of the district manager and are assigned to allotted territory within that district as designated by the district manager.

R. S. Hale:—In Boston use is made of rather complicated forms of rates, and the reason they are complicated is that they include practically every condition that may arise. In the last five years no special contracts whatsoever have been made outside of the printed forms. That fact makes it very satisfactory in dealing with customers, because the customer can be told that he obtains exactly the same treatment as every one else. There are of course, some old contracts, made from five to ten years ago, which are still in existence, but no new ones are made except those on printed forms, and that is a very great advantage in dealing with customers, and satisfies them that they are really getting the best rate.

Moreover the contract forms have been much simplified because probably 95 per cent of the customers like a very simple form of contract, in which they merely apply for service at standard rates as they shall exist from time to time. If the rate is reduced the customer gets advantage of the reduction without signing any new contract. On the whole the plan works very satisfactorily indeed. The customer himself signs the simplified form of agreement, leaving to the salesman whether he shall have the long term or the short term rate, and, on the whole, the salesman gets the confidence of the customer in a way that is probably not possible in the blanket forms of contract.

About five years ago the Boston Edison Company had five or six district offices that covered perhaps 500 square miles. Maintaining these offices meant rent, managers, etc., and they were closed up as quickly as possible. Now the salesmen visit these different districts and canvass, merely having desk room and telephone. They telephone in their orders for the day and call up again in the afternoon; they have no office where people come but they go to the customer and get the business.

Most of the territory served by the Boston company has been acquired by consolidations with different companies, and of course, the managers of the older companies were retained, usually as salesmen as well as managers. In almost every case the man was rather a failure in his district because he knew the people so well that he could not sell electric light very well. I think that a salesman who knows his customers intimately is not

a successful salesman. These same managers when transferred to some other districts became successful. Where a man was not known—where he had to make the acquaintance of the people—he secured the business, and I think the science of that is change. The keynote of salesmanship is change. It is necessary to effect changes, first the district offices and then the salesmen. It is like newspaper advertising—keep constantly changing is the keynote of new business.

C. A. Littlefield:—The paper is advantageous in that it emphasizes the relationship existing between the commercial illuminating engineers, if such a term can be used. Too often the importance of the one over the other is emphasized, and in the desire of engineers to secure a certain illumination value or artistic effect, economy of service is lost sight of with the result that the lighting bills become high or exorbitant; the customer is dissatisfied, and the object of the engineer who laid out the equipment is either lost entirely or rendered ineffective through the customer discontinuing the service or materially reducing the installation. Often it is necessary to correct installations, laid out unwisely, not from an illumination, but from a commercial standpoint. The equipment may have been artistically laid out and beautiful effects produced, but the all-important question as to the amount of the lighting bills stands out glaringly and the final result is that all the studied effects are lost because of the reduction either in the size or number of units that must be accomplished to reduce the installation. Those bills are hardest to check which pay for something intangible, and there is nothing more intangible than illumination. The average householder is not sufficiently educated or willing to separate himself from his "filthy lucre" to pay for those intangible but artistic effects. Consider the case of a kitchen. When the installation in this part of a building is larger than conditions required large bills will certainly result. The people employed for work in the kitchen care very little as to the size of the bills. No care will be exercised to discontinue the use of a lamp in one part of the room when the work at that point ceases, and lighting another at some other point when working there, the result being that practically the entire in-

stallation will be in use all the time, whether required or not, and high bills will be the outcome. The food will be cooked and seasoned just as well, the dishes washed thoroughly or slovenly, depending upon the personal efficacy of the one doing the work, whether the kitchen has been equipped to give a definite illumination generally or at any specified point. The result of those high bills will be a complaint to the lighting company, and when an investigation is made by the company and the servants asked as to the use of the kitchen equipment, excessive burning will, of course, be denied. Then, possibly economies in other parts of the house will be tried the result being some poor lighting conditions, where the equipments will least permit a change, unless all thought of artistic design is abandoned. If, however, an excessive equipment had not been provided at a point where no control was exercised, the bills would have been normal, the customer satisfied and no change made in the artistic design, where in reality no unusual amount of light was used.

The minimum form of charge does not appeal to me and nothing in the way of rates has been found more repugnant to the public at large. Theoretically there are excellent reasons for the justice of such a charge, but whether it is called a "readiness-to-serve," a "stand-by," a "minimum" charge or what not, it is in reality the one and the same, and it is just where theory and practice are at variance. Gild it as you wish with descriptive phrasing, the customer when receiving such a bill is convinced that he is paying for something he has not received, and thereby becomes thoroughly dissatisfied. Electricity is a commodity to be sold the same as any other article of commerce, and just as we make it popular and easily purchased, do we increase the demand for that commodity. Suppose, for instance, that to cover his loss from breakage, decay, etc., and to be always in "readiness-to-serve" fresh eggs, a grocer would refuse to sell less than a dozen eggs, or a smaller number at less than the dozen price, how long do you think he would remain in business? Do you think that the average housewife would continue to deal with him when she learns that the grocer is compelling her to pay his losses when she is purchasing in small quantities? The law of

averages will enable that grocer to sell one egg, if necessary, on the basis of the dozen price at a profit, and a lighting company can do the same. Just in proportion as it is made easy for the public to do business with the lighting company is the number of satisfied customers increased and a large number of customers who are friendly disposed toward the company is its most valuable asset.

H. W. Moses:—The territory of the company with which I am concerned covers 35 cities and towns outside of Boston. Some time ago an illuminating engineering division was started within the company and the services of Dr. Louis Bell, as consulting engineer were obtained. Under him were two or three assistants. Circular letters were sent to all the customers stating that the division was at their disposal. The success has been great. Suggestions have been made to more than 1,200 customers and more than 150,000 tungsten lamps have been added. Many customers have become interested in illuminating engineering work, notably the School House Commission of Boston, in obtaining the best results in school-room lighting.

A new line of development, that of increasing the income from existing customers, is just being started. Doubtless there will be a drop, temporarily, in the number of new customers obtained; but, by pushing the business among existing customers, the result will a greater income at a minimum of investment. It will take a tremendous amount of advertising and hard work, but the company is well equipped to carry along this work. The solicitors will make a house-to-house canvass of every existing customer to find out if he is satisfied as to his bills and lamp or motor service arrangement and to see if there is not some other device which may be used. This development work will consume probably several months, but the company will get in close touch eventually with the customer, know him better and sell him more.

It has always been the custom of the company to draw a dividing line between the small and the large business. This division is set arbitrarily at 30 kilowatts. The large business is handled by the general agent's department, with seven as-

sistants whose duty it is to call upon all large customers, both existing and prospective ones. They make friendly calls three times in three months, simply to keep in touch with the customer and see that he is satisfied. It has been demonstrated that a satisfied customer always produces new ones and it is the policy of the company to work along such lines.

J. D. Israel:—Mr. Hale stated that he did not think it advantageous for the salesmen to become well acquainted with the customers. I disagree with Mr. Hale on that point, but I agree with him on the necessity of changing the district of the solicitor from time to time, but not necessarily changing the district manager. We find that some solicitors are not suited for certain localities but yet may prove of much service to the company in some other district. In such cases we make a transfer of solicitors.

This district manager should become well acquainted with the people and the prevailing conditions of the district over which he has jurisdiction.

Some criticism has been made of the minimum charge. We feel that it is justifiable on account of the ready-to-serve and maintenance expense attached to each connection.

With reference to the criticism of discounts on large installations, it will be found on analysis that the large installations play their part in filling the valleys and broadening the peak of a load diagram.

In Philadelphia the solicitor has no authority to change the rates. There is a regular schedule of rates to which the solicitors must adhere. The scale of discounts is printed and is public property, and anyone has ready access to the information.

G. H. Merrill:—I wish to refer briefly to the curves shown by Mr. Jones which give the connected load and kilowatt-hours output month by month. With the beginning of tungsten lamp installations the kilowatt-hour consumption is shown to become relatively less per kilowatt of connected load. This can only mean that the customers have a lower lighting load factor after installing the high efficiency lamps than before. It is improbable that this is a result of using the tungsten lamps for shorter periods than the carbon which they replaced but rather that only

those carbon lamps which are used for long periods each day were replaced with tungsten lamps (of perhaps somewhat less total wattage) while lamps of low efficiency and high wattage were allowed to remain in the out-of-the-way places. These latter lamps add relatively a great deal more to the connected load and the maximum demand than to the kilowatt-hour consumption because of their short period of use.

It seems, therefore, that it would be to the best interest of the central station to see that lamps of low wattage are used where the period of use is short. Undoubtedly 25-watt tantalum lamps would give sufficient light in a great many cases in which 56-watt carbon lamps are now used, or, if it be desirable to have more light, 25-watt tungsten lamps could be used. The customer's lighting load-factor would be improved considerably by such practice and the number of killowatt-hours sold per killowatt of maximum demand, or per kilowatt of connected load would be increased thereby.

L. J. Auerbacher:—Allow me to state in this connection that I believe we have been neglecting the biggest customer, and that is city lighting. I feel that our streets exhibit the worst exhibition of lighting to be seen.

W. T. Blackwell:—The appropriations in New York are governed by the Board of Estimate and Apportionment, and the retiring Board has provided only sufficient money to care for the existing equipment, and has made no provision for additional street lighting.

H. T. Owens:—I should like to call attention to the great improvements which have been made in the Western cities in ornamental public lighting, which is paid for by the local merchants. This is in great contrast to those cities in the East where the matter has been almost entirely neglected. In New York, Boston, Philadelphia, and other large cities, special lighting on prominent thoroughfares has been supplied by the municipality, but where the city officials cannot or will not do this the live men in the gas and electric light companies have a fertile field for new business.

J. D. Israel:—With reference to street lighting, we think we have a generally well-lighted city, with a more even distribu-

tion of illumination throughout than is to be found elsewhere. The Market Street plan of lighting was decided upon after actual tests and experiments had been made with the various systems, and we feel satisfied that the Electrical Bureau has accomplished good results.

A. J. Marshall:—From numerous visits to Philadelphia I have been led to believe that the street referred to is one of the best lighted thoroughfares in the country.

B. J. Aplin.—As an example of well-engineered city lighting I would call attention to the arc lighting installation of upper Seventh avenue, and also Broadway, New York City, which as to economy and aesthetic effect, I believe, will compare favorably with that in any other city in this country or Europe. No doubt within the near future the main thoroughfares of this city will be illuminated by arc lamps and the lesser traveled ones with high efficiency incandescents.

Mr. Jones states that often business comes to the central station. This is true, but companies engaged in the distribution of a commodity of this character must needs take the initiative and through their agents advocate the use of the latest design in lighting appliances. The growth of a factory section in densely populated cities will present opportunities to the illuminating engineer for the more scientific distribution of artificial illumination affording greater protection to the eyes of those therein employed as well as a saving in energy consumption.

The central station district office manager, is enabled to keep in close touch with the requirements of those in his vicinity. An irritated customer calling can here reason out with him personally the knotty problems that occasionally arise and through courteous and considerate treatment a friendliness for the station service is promoted.

A paper presented at a meeting of the New England Section of the Illuminating Engineering Society, Boston Mass. February 11, 1910.

FACTORY LIGHTING.

(Abstract of address.)

BY L. B. MARKS.

New England is noted for its factories, and a splendid opportunity exists in this section of the country to apply the principles of illuminating engineering in the remodeling of existing installations. But sometimes the ones that are able to have the proper things are the last to adopt them; and frequently even after they have been set aright they will go back to the old method. This is especially true of factory lighting. The average workman is used to a certain kind of lighting, a drop lamp over a machine, usually within a foot or two of the spindle or of the working surface. Substitute for that drop lamp almost any other method of illumination and he is apt to complain. He will say it is not as good as the old way, even though the old way was destroying his eyesight.

The general subject of factory illumination may be considered under two heads; namely, natural and artificial lighting. While it is true that a large percentage of factory work is done during the day, still in some cases much work is done under artificial light. We all know that sometimes it is impossible for the workman to do the same character of work by artificial light as by daylight, and in some cases it is impossible for him to do his work at all by artificial light. Is there then, any inherent defect in the artificial light which prevents the workman seeing by that light as well, or nearly as well, as he can by daylight? We have found from practical experience that, though managers have said it was simply impossible to light a certain class of work by artificial light, with proper application of the light it has been possible to do so.

Those of us who have had occasion to visit factories, will know that the basements are frequently poorly lighted, that workmen are compelled to labor altogether by artificial light.

There is a perceptible eye strain, which the managers do not seem to appreciate, otherwise they would be the first to want a change in the character of the lighting equipment. Money would be no object, for the spending of a comparatively few dollars would bring about a change which to them would be worth hundreds, perhaps thousands.

One of the devices used advantageously in reinforcing daylight in certain dark parts of a shop is prismatic glassware, or so-called daylight prisms. In one mill, by the substitution of these daylight prisms, it was possible to dispense with eight skylights, thus giving the proprietors 10,800 square feet of additional well lighted floor space. The rest of the shop was better for the change too. The economic value of this is not easily determined, but of far greater importance is the change that is brought about in the ability of the workman to do good work continuously.

There is great difference in the diffusing and directing power of different kinds of daylight glassware. We all know that clear glass windows, though they permit light to enter a room do not direct it; whereas certain forms of prismatic glassware direct it one way, and other forms in an entirely different way. It is the duty of the illuminating engineer, then, so to select glassware and design windows to obtain the best results not only in the amount of light which enters the factory building, but in its direction. I lay great stress on the latter point because it applies just as strongly to daylight as it does to artificial light.

It seems clear to me that any illumination which results in a series of bright spots on a dark background is poor illumination. In other words, strictly localized lighting by lamps enclosed in opaque shades or reflectors is apt to be poor illumination. There is no ultimate economy in that class of lighting, even though there may be great economy in the initial and operating cost of such an installation for the reason that the operator, in my opinion, is not able to do continuously as good work as he could if the illumination were of a different character.

In one of the factories investigated the actual general illumination throughout the shops at night was only about one-fourth

of a foot-candle,—in some departments as low as one-tenth of a foot-candle. There was a restricted field that was highly illuminated by the drop lamps, where the intensity of illumination was all the way from 10, 20, 50, 100, up to 250 foot-candles. The great difference in light intensity between the general and the local fields undoubtedly brought about severe eye strain.

I have had the opportunity of comparing the results of an installation of this character with one in which the general illumination was not restricted as in the case of the drop lamp installations, but was obtained by directed light from lamps hung some six feet or so above the floor. In this particular case it was like pulling teeth to convince the management that it would actually pay to spend two and a half times as much money for current, to throw out its old system and put in something else. But it was finally done, and we have had two and a half years of experience with this installation with splendid results.

I make the plea here to you to consider seriously the question whether the localized, highly-restricted illumination which is used in the average factory is the proper thing. Is it fair to the workman, and, if it is not, are we not the people to take the lead in showing the community that the workman's eyes are suffering? Never mind whether the managers see ultimate economy in it or not, that is bound to come, it seems to me; but let us take up the problem from the humanitarian standpoint. If it is not right, let us band together and correct it. We members of the Illuminating Engineering Society owe it to ourselves and to the community to find out what is right, and if any commercial organization supports a method of illumination which we believe is wrong, if we are convinced of the fact, let us advise the public to that effect.

The Chicago Section of the Illuminating Engineering Society met in the Chicago Room of the Great Northern Hotel for luncheon at noon, Friday, February 18, 1910. Chairman Scheible presided.

Secretary Beebe announced the temporary abatement of the Society's initiation fee adding that he thought this fact would increase considerably the local membership.

Chairman Scheible then announced that Preston S. Millar, general secretary of the society, would talk on "Recent Developments in Illuminants."

Mr. Millar reviewed the developments of the past decade in all commercial forms of artificial illuminants and presented lantern slides and data showing the performance and present status of each of the illuminants referred to. In addition, certain new or unusual forms of lamps were passed among the audience for examination.

The Chicago Section of the Illuminating Engineering Society met in the Chicago Room of the Great Northern Hotel for luncheon at noon, Tuesday, March 15, 1910. Geo. R. Keech, presided.

The subject under discussion was "The Necessity for Illuminating Engineering in Small Cities," by Mr. J. R. Cravath.

J. R. Cravath:—My experience is that illuminating engineering in small towns represents the extreme of the art. We usually look to the cities to represent these extremes, but in this case it seems to be reversed. I have seen some of the best illuminating engineering in small towns in the early stages of development, and I am sure I have also seen some of the worst. There is need for good illumination in small towns, because the average country merchant or owner of a home has not much surplus to spend on lighting, and for reasons of economy alone it is quite important that he be given particular attention. The status of illumination in a small town depends usually almost entirely upon the lighting company in the town. In other words, the people naturally look to them for advice, as they usually initiate any improvements. If they are progressive, and lead

their customers to put in modern installations in order to get the best results for their money, you can very soon see improvements. The small town is quicker to respond than the city.

In the small stores in a country town, the typical arrangement for years was to have one or two arcs to light a store, 25 or 30 ft. wide, or else a couple of rows of bare incandescent lamps on drop cords, hung about the level of the customer's eyes. There has always been an apparent aversion on the part of the country store-keeper to use any glassware or reflector to give better results. These stores were originally wired at minimum expense, *i.e.*, with plain drop cords and bare lamps. It was often hard to persuade them that it pays to invest money in reflectors. This condition holds true, not only with electric light, but also with gas and isolated gasoline plants. Gasoline plant manufacturers have done very little to try and get better results from their system. The laxity of the gasoline plant manufacturers in this regard has been helpful to central station companies, as the ability to obtain better results with the same expense by the use of proper glassware, etc., with either electricity or gas has helped these companies to compete with gasoline lighting on the ground of economy. There are some towns in Illinois and neighboring states where a bad installation in the down-town district is rather the exception than the rule. Tungsten lamps are hung high with efficient reflectors, and deliver the light on the counters where it is needed, and conditions in general are very good, a state of affairs brought about by strong competition.

In residences in country towns the conditions are similar to those in the cities. People generally are not awake to perfected apparatus. The dealers in small towns say there is still demand for cheap fixture with curved arms, with the lamps pointing out at an angle.

The necessity for the old style chandelier is practically gone. In fact they are a useless expense, and are inefficient after they have been put up. I think on the whole we can say that illuminating engineering practice in country towns compares favorably with that of the average of the larger cities.

Mr. Fitzgerald:—In Gary we recently had up the proposition of properly lighting the new City Hall. I took the members of

the Board of Trustees to South Bend, Indiana, to see the illumination at the Studebaker office building, one of the best samples of good illumination in that part of the country. We planned our lighting system from the ideas we gathered from the Studebaker installation. The plans called for the use of five 100-watt units, tungsten lamps. Running short of money before the lamp question came up, instead of using the tungsten lamps planned they installed 40-watt tantalum lamps. The result was not what was intended. Some of the clerks now use drop cords from the fixtures in order to have lamps over their work.

A paper presented at a meeting of the New York Section of the Illuminating Engineering Society, New York, March 17, 1910.

THE RELATIONSHIP OF DECORATION TO THE ILLUMINATING ENGINEERING PRACTICE.

BY C. R. CLIFFORD,

In considering the subject entrusted to me, we must concede at the outstart that the relationship, heretofore existing between engineer and decorator has been more theoretical than practical. The illuminating engineer has been always too busy with the installation of electric plants, the illumination of mills, big department stores, institutions, and public buildings, to give to the study of decoration any adequate consideration.

As a result, the illumination of the home is undertaken in a perfunctory spirit by somebody or other under the architect or decorator who fixes his outlets according to order, a mere mechanic on the job. Such a man naturally occupies a negative position.

There is a vast undeveloped field of usefulness in the illumination of the modern home and neither the architect nor the decorator is competent to conceive its possibilities.

Whatever is good in decoration springs from the consistent relationship of color and form under certain light conditions. The decorator appreciates the charm of these conditions which, for want of a better name, he calls atmosphere; and I know of no one more competent, with proper study, to create this atmosphere than the illuminating engineer. As the choice of color is guided by the conditions of light, the character of light is obviously of the utmost importance; and yet the subject is but vaguely comprehended. The technical man has given his life to economic rather than to psychological consideration. He has knowledge of power and energy, but he smiles indulgently and with smug complacency at the mere idea of æstheticism. And yet the field is broad and profitable, and it would be a great relief to the decorator to be able to give over to you the illumination responsibilities in all that the term implies.

If you are not already recognized as factors it is because you have not awakened to your great powers. And what constitutes artistic illumination? Art is simply the expression of one's belief in the beautiful. It is a nice problem to decorate in a way to give true balance, for there is always the danger of overdoing. No matter how great one's admiration for a thing, there is always a final point of satiety where the desire needs rest.

A woman may love flowers, but in the season of flowers, when all nature supplies an over-abundance and the visual sense becomes saturated and satiated, the home that is furnished in cool neutral tones is a grateful and restful retreat, a relief to the eye over-burdened with color. So with light.

In ninety-nine cases out of a hundred the decorator furnishes the house and selects his colors by daylight; and in order that he may preserve the purity of the colorings by night, he is predisposed to the use of artificial white light—a continuance of daylight effects. And yet nature provides restfulness, which comes with sundown. Why not follow the work of nature and into the home at night carry the quiet and peace of eventide, to rest one from the glare of perpetual day? If you are to impart the comfort-giving, pleasure-giving qualities which impel admiration, you must grasp the subject from the decorator's standpoint and give him help. Above all else you must have imagination, the motive power of all enterprise, the impetus, the thought behind the act. In great feats of engineering, imagination is the fulcrum on which the spirit of genius is lifted to success.

The joys of the home, its ceremonial functions, its dinners and dances, even the quiet of an evening with the reading lamp, may be all enhanced or marred by your knowledge. It is not a matter of mathematics that is brought to you, it is a subject to which you must apply imagination that evokes the æsthetic sense.

Instead of height and width, length and breadth, consider occasionally the light necessary according to the individuality of the room. Consider the effects of reflection, the value of cove lighting by diffusion, the usefulness of the ceiling as a reflecting agent.

Consider the candle-power for a room only after calculating the probable color treatment of the room. It is an elemental

principle, for example, in house decoration, to select warm colorings for the north room on the theory that in the north room we have a natural cold light, and warm colors are preferable in the decorations. The electrician can, therefore, assume by deduction that he needs a greater amount of illumination in this north room because the warm color tones used in the decoration of this room are factors which absorb light.

Consider the reduction of illumination by the addition of shadow-casting furniture and light-absorbing upholsterings and curtains.

Consider the usefulness of low placed lamps for the dining-room, the practicability of bookcase and closet lamps and high lamps at the bureau reflecting the image, and the blaze of light in the dressing room.

Consider the character of the drawing-room and reception-room, to which all ages and conditions of humanity have access.

Consider, independent of color, that dull and lusterless walls and velvet stuffs absorb light, while, highly finished fabrics or woodwork reflect light.

Consider the loss of illumination by reflection, and never lose sight of the fact that, while it is necessary to have sufficient light where needed, there is a danger equally serious in over-lighting and destroying the pictorial beauty of a room.

Consider the features of interest, the articles of special beauty and use your lights to accentuate their charms.

Consider that without shadow we have poor perspective. The illuminating engineer who throws light into the remotest corners destroys variety and pictorial character.

The danger to good decoration is not only in over-decorating but in over-lighting. The most effective room is the room illuminated with various degrees of strength.

We want shadows; we want light and shade. It is all right for the factory and showroom to have a penetrating white light that reveals every thread of the texture and preserves the integrity of every color. It is all right for the hospital and the operating table, but for universal home use, no.

And, before you have given much study to your subject, you

will realize the crushing disadvantages of impracticable and insufficient outlets.

Give plenty of outlets to a room. It will add to the selling value of the house. Thousands and hundreds of thousands of dwellings are built each year on the country byways and city avenues evidently to be sold to someone who has nothing to do with their construction, and in all such buildings we find, not only a heedless regard for light, but a contempt for practicability.

Fortunately we are able to meet the utilitarian problem by stringing wires to movable lamps; but why employ the makeshift which is so obvious an attempt to correct the errors of the engineer?

Consider always the character of the room and its uses. There are times when it is pleasanter that the truth should be half told, and the soft refulgent glow is better than the glare that is merciless.

The home is the theater of life. Then give us the lights that make joy and peace, happiness and repose.

Go to the mimic stage and observe the great work that is done there. No longer does the orchestra give the key to the emotion. We are not aroused to an extra heart beat by the shiver-music of the strings. It is the man with the light, and why? Because the play is always seen by artificial light and whether the light simulates nature by daylight or moonlight, the colorings on the stage are so selected that they are beautiful under the lights used and are not a discordant element, a sacrifice to the demonstrations of illumination.

Remember always that our social functions are at night, and even in the afternoon affairs miladi lights the candles and draws the shades; and the lights should be an effective aid to the colorings and not an influence emasculating and discordant.

All of this is known to the decorator. He perceives daily the possibilities of light but he knows not how to obtain them, nor does he know the man who is qualified to help him. It would seem, therefore, as though the illuminating engineer should qualify as the one authority, not only upon all that pertains to the production and installation of light, but to its introduction through the medium of the chronologically accurate fixture.

The study of fixtures cannot be undertaken superficially. Immigration, commerce, the industrial arts, religion and politics have carried into the home for countless centuries what we have learned to regard as period furnishings and period styles; and to understand the periods you must comprehend not only the historical relations, politics and commerce of nations, but the progress of civilization, art and industry.

You must follow the Renaissance developments through the Louis XIV, XV, XVI and Empire régimes. You must follow the inroads of the Dutch and her Flemish predecessors, the developments of the English from Henry VIII down to George III.

From the Egyptian to the Art Nouveau there is a span of thirty centuries, and to furnish the fixtures in the Elizabethan, Jacobean, Colonial, Oriental, Queen Anne and the innumerable other styles means study.

And what of the mystery of your lights? Did you ever stop to think of the psychology of light? Chromotherapy is the science based on the effect of colored lights on the human body. For years Schopenhauer, as well as Herbert Spencer, searched for an explanation of the effects of music on the emotions, and yet the effect of color upon the nerves of nervous people is more distinctly shown than the effects of music.

The Dutch savant Van Bliervliet holds that the senses directly affected by color furnish absolute nourishment to the intellectual factors, and experiments made simultaneously upon a dozen people chosen haphazard, showed that the most intelligent were those most easily affected by color or music.

Physicians have discovered that nervous prostration may be successfully relieved by color, especially violets, blues and greens. Reds are exciting, orange and yellow stimulating.

It is well to consider that there should not only be no glare in the study to disturb one, but that a blue, green or violet light should be used. We look for the gaiety of orange, yellow and red in the drawing-room. Hence the popularity of the yellow of candlelight diffusing joy. It is the sunshine of night.

Nature provides vast fields of green because it is favorable in its effect upon animals.

Experiments show that men of extreme sensibilities exposed

to red light show excitement, and increased muscular development. I commend to your study the work of the illuminating engineer employed upon the stage of the play "The Harvest Moon." If there is doubt in your mind of the psychological influence of light and of its great interest to the public, I advise you to watch this audience spellbound in its interest.

It is not the white light alone that is wanted, it is not the purity of color value that we must consider in lighting, it is first the object of the room and then the practicability of the outlets; then the influences as expressed by the volume or the color of your light.

Take a lesson from the influence of light on this audience and Vavin and consider if the influences of your work may not extend beyond the purely mechanical.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. V. APRIL, 1910. NO. 4

MINUTES OF COUNCIL MEETINGS.

MARCH 10, 1910.

At the regular meeting of the Council held at the office of the Society, March 10, 1910, there were present Messrs. E. P. Hyde, President, Louis Bell, J. S. Codman, J. D. Israel, Bassett Jones, Jr., A. S. McAllister, L. B. Marks, W. C. Morris, E. B. Rosa, and P. S. Millar, General Secretary.

After transacting routine business, the following Committee appointments were announced by the President and approved by the Council.

Committee on New Members:—J. Robert Crouse, chairman; W. H. Gartley, H. B. Dates.

Committee on Progress:—Louis Bell, chairman; Geo. S. Barrows, Percy W. Cobb.

Executive Committee:—E. P. Hyde, (*ex-officio*); W. C. Morris, P. S. Millar, L. B. Marks, E. B. Rosa.

Committee on Lecture Course:—E. P. Hyde, chairman; Louis Bell, W. H. Gartley, L. B. Marks, C. H. Sharp, W. D. Weaver.

The following applicants were elected to membership:

BEAKER, C. H. G. JR., Newburg, N. Y.
BEAL, A. R., Newburg, N. Y.
THOMSON, A. M., Boston, Mass.
BERNHARD, FRANK H., Chicago, Ill.
MCMILLEN, R. B., Chicago, Ill.
STAVE, THEO., New York, N. Y.
GLUCROFT, S. H., Brooklyn, N. Y.
WARDLAW, GEO. A., New York, N. Y.
STOCKHAUSEN, A. K., Dresden, Germany.

APRIL 14, 1910.

The regular meeting of the Council was held in the office of the Society on Thursday, April 14, 1910. There were in attendance Messrs. E. P. Hyde, President, Jos. D. Israel, Bassett Jones,

Jr., A .S. McAllister, L. B. Marks, and P. S. Millar, General Secretary. There were present also by invitation Mr. G. A. Wardlaw, Chairman Committee on Editing and Publication and Mr. Robert J. Crouse, Jr., Chairman New Membership Committee.

After consideration with Mr. Wardlaw regarding the many requests for sample copies of the TRANSACTIONS it was decided to select a few representative papers and have them bound in a special edition of 500 copies to meet such demand.

The price of individual numbers of the TRANSACTIONS was increased to 75 cents to non-members and 55 cents to members who desire extra copies.

Mr. Crouse presented in detail the New Membership Committee's plan for increasing the membership. This plan met with the approval of the Council and the Committee was authorized to proceed.

The Finance Committee presented a report on matters within its province. The Committee on Lectures reported in some detail regarding plans which were being formulated for the conduct of the Lecture Course on Illuminating Engineering at Johns Hopkins University. The Council approved actions taken by the Committee and authorized the Committee to perfect the plans outlined.

An invitation from Johns Hopkins University to hold the 1910 Convention at the University in Baltimore on October 24th and 25th was considered and accepted.

Various other routine matters were considered and disposed of. The following applicants were elected to membership:—

VAN DER SANDT, CURT, Germany.
SMITH, GEO. P., Union Gas and Elec. Co., Cincinnati, O.
STEVENS, EUGENE, Gen. Elec. Co., St. Louis, Mo.
HUTTON, DONALD J., Mexican Light and Power Co., Mexico City.
LIVOR, J. C., Boston, Mass.

SECTION MEETINGS.

NEW YORK SECTION.

This meeting was held on March 17th in the United Engineering Societies Building. President Hyde presided and there was

an attendance well above the average of the New York Section. Three papers were presented and discussed respectively, "The Relationship of Decoration to the Illuminating Engineering Practice" by C. R. Clifford, (March TRANSACTIONS), "Color Measurements—A Resumé" by Herbert E. Ives and "A Standard for Color Values—The White Moore Light" by D. McFarlan Moore.

NEW ENGLAND SECTION.

"The Lighting of a Hypothetical Shoe and Rug Store," was the subject of discussion at a meeting of the New England Section held in the Auditorium of the Edison Electric Illuminating Company of Boston on March 14th. The discussion was opened by Messrs. L. Brent Foster and Benjamin T. Bean.

A meeting of the New England Section of the Illuminating Engineering Society, was held at Boston, Mass., on April 11, 1909, at 7:50 p. m. The first paper presented was on "Street Photometry," by Dr. Louis Bell. This was followed by a paper on "School Room Lighting," by Mr. B. B. Hatch. After the papers were given, a discussion took place. The committee on the revision of by-laws gave notice of contemplated changes which would be voted upon at the next meeting. There were 30 present.

PHILADELPHIA SECTION.

A joint meeting of the Philadelphia Section with the Philadelphia Section of the American Institute of Electrical Engineers was held in the Assembly Hall of the Philadelphia Electric Company on March 14th. Dr. Hoadley and Mr. J. T. Maxwell presided. The following papers were presented:—

"The Generating System of an Electric Lighting Company," by A. R. Cheyney.

"Distribution," by D. F. Schick.

"Electric Lighting Within the Consumer's Premises," by Harold Calvert.

These papers were discussed by W. C. L. Eglin, Northrup, H. C. Snook, R. B. Ely, E. P. Hyde, President I. E. S. and P. S. Millar, General Secretary I. E. S.

CHICAGO SECTION.

A special meeting of the Chicago Section was held at the Great Northern Hotel on March 24th. Mr. A. J. Marshall, Secretary

of the New York Section addressed the meeting on the subject of school room lighting along the lines of the paper by Messrs. Marshall and Knight presented before the New York Section at a February meeting.

INCREASE IN MEMBERSHIP.

Our Membership Committee has been very active and not without excellent results. At the meeting of the Executive Council on July 22d, 242 members were admitted, and up to the present time the total number of applicants received by this Committee is 367. This bespeaks of energy and interest. A good many of the present members have been "solicited" by the Membership Committee in order to keep their enthusiasm aroused to the possibilities of extending the membership.

Why should we not hope that every man eligible to membership should enjoy membership? The facts brought out by the Membership Committee is their Campaign are that too many men who should be members have not been invited to become members. The life of any scientific society is dependent upon its membership. Its membership should include every one interested in the objects of the Society. Mr. J. Robert Crouse, 1818 East 45th Street, Cleveland, Ohio, Chairman of the Membership Committee and his office will gladly accept the names of any prospective applicants which you may have in mind. Although we have increased our membership over 33 per cent., still if each member would by personal contact and co-operation with the Membership Committee, interest at least one person, our membership would increase in much larger proportion. Please give this matter your consideration and support.

A paper presented before meeting of the New York Section, March 17, 1910.

COLOR MEASUREMENTS OF ILLUMINANTS—A RESUME.

BY HERBERT E. IVES.

Before our knowledge of the effects of artificial light is satisfactory we must solve the problem of the part played by color. Daylight is commonly considered the ideal illumination, and the age-long adaptation of the race to it would support this belief. Nearly all artificial lights are greatly different from daylight, among other respects in that of color. The practical results of this are seen whenever we attempt to work with colors under artificial light. Harmonies made under these conditions do not hold in daylight, and vice-versa. This difference can be met, to a certain extent, by designing our color schemes to fit either or both illuminations. But after we have thus masked the differences for practical purposes an important question remains. This question is whether lights much different in color from daylight are harmful to the eye purely because of the large color difference. At present it is difficult to separate the various possible harmful effects in artificial light and determine their relative importance. High intrinsic brilliancy, excessive infrared radiation, and poor color probably all strain the visual organs. It is only by the acquisition of exact data that the part played by each of these several factors may be evaluated.

In the present paper attention is devoted to securing as exact information as possible on the difference in color, between day and artificial light. A review is made of the various measurements of daylight and artificial illuminants that have been obtained by different observers and by different methods. This review was prompted chiefly by the existence of marked inconsistencies between the measurements of the writer by one method, and certain other measurements by another observer by another method. In the attempt to compare both these sets of figures with those of other observers the need was quickly recognized of reducing all figures to common units. This done, it has been

possible to arrive at figures giving more accurately, it is believed, than heretofore, the color relations of many illuminants, natural and artificial.

Two methods have been used to measure color in illuminants. First, the spectrophotometric method, in which the relative intensities of the two spectra are measured color by color, or wave-length by wave-length. Vogel, Koenig, Crova, Pickering, Koeltgen, Nichols and Franklin, and others, have made measurements by this method. Second, the method of color mixture, in which an actual match is made with the observed illuminants by a mixture of certain primary colors. Measurements of this sort have been made by the writer. The results obtained by the two methods can be compared, with certain limitations, and this will be done. First, however, will be considered the spectrophotometric measurements.

Daylight measurements have been subjected to two sources of uncertainty. First, the variability of daylight itself. Second, the lack of a common standard of comparison in different sets of measurements. To these should be added, as a fruitful source of error in the spectrophotometer, the great difficulty of making accurate comparisons of lights widely differing in intensity gradient from end to end of the spectrum.

As to the variability of daylight, we apply this term to everything from a deep blue sky to the orange light of the sun near the horizon, to the clear sunlight of summer noon and to the light of sun and sky as diffused and reflected by mist and clouds, these latter also reflecting the color of earth and foliage. Daylight is not therefore of definite color. Certain qualities of daylight, however, are fairly definite in character, much more definite, in the writer's opinion, than we are apt to think, having in mind the more variable kinds of sky and sunlight. These kinds of daylight, which are reasonably constant in character, are clear noon sunlight in summer, and a clear blue sky, near the zenith. "Average daylight" probably lies between the clear blue sky and the light of the sun through the greatest thickness of air it has to penetrate, since clouds and mist owe their light largely to the sun and sky behind them. Without considering any measurements, there is a strong *a priori* reason for believing the light of the high sun near the mean of daylight illumination, for it is

well established that the blue of the sky and the yellow of sunset are complementary in color, each being produced by the same cause,—scattering of the sun's light by passage through the air.

Fortunately most of the available measurements have been made on clear sun and blue sky, largely of course because of the greater definiteness of these two over other kinds of daylight. For the change of color of sunlight by passage through various thicknesses of atmosphere we have an investigation of Abney which confirmed Rayleigh's theory that the scattering of light by small particles is the cause of this change. If then we bring together all the measurements of clear sun and clear blue sky we should have, if the above opinion as to their definiteness is correct, figures derived from very nearly the same skies and sun. If we combine with the sunlight data the work of Abney referred to we should obtain the extreme to which sunlight varies toward yellow. Then knowing the extremes between which daylight varies we shall be in a position to discuss the problem of striking an average.

In order to bring together all the available measurements it is necessary to compare them all with a common standard. This is a hard matter, for we find that practically every observer has employed a different artificial source, frequently one whose color is not a definite thing, often one which has not been compared with any used by other observers. We thus find the "gas flame," "a normally burning incandescent lamp," "petroleum," "the Hefner," "the Carcel," "acetylene" and often there is no adequate statement of the conditions, such as type of burner or grade of oil, or watts per candle, upon which color depends. Aside from the consequent difficulty in putting these measurements in terms of each other, there arises the question,—what standard should be taken? Why should any one of the above be chosen rather than another?

The standard here used has not been employed before, but appears to the writer to be the most logical. The measurements are expressed in terms of energy, that is, as a bolometer or other radiation meter would give them. As will be seen, not only do we so free ourselves from any one artificial illuminant, but

some of the most important relations of light and color with other phenomena are brought out.

In order to so express existing measurements it is necessary to know the energy distribution of the comparison standards. The Hefner lamp, probably the most definite in color of any flame standard, has been found by Angstrom and Leder to agree visually with a complete radiator or black body at a temperature of 1,830° absolute. We may by using the Wien-Planck equation calculate this distribution of energy. A flat acetylene flame has been found by Dr. E. P. Hyde to agree visually in color with a black body at about 2,330° absolute. This checks closely with direct comparisons made with a Hefner by the writer, taking the mean of results from several acetylene-Hefner ratio closely that obtained by other observers. The acetylene flame not being a fixed thing, as is the Hefner, this transformation to energy units is subject to a small uncertainty, for in no case have the actual flames used been matched against a black body. The error, however, will amount to a very few per cent. at the ends of the spectrum. The relation of the other standards that have been used, to these two, has either been determined, or can be estimated fairly closely so that we can use nearly all the daylight measurements which have been published.

Proceeding now to the results of expressing the available measurements on one scale, in Fig. 1 are plotted the energy curves of the Hefner, and of acetylene, while the various points across the middle of the figure are clear sunlight values as obtained from the spectrophotometric work of Koettgen (Hefner), Koenig (gas), Vogel (petroleum), and the present writer (acetylene) each indicated by a different symbol. The observations are plotted, according to the usual convention where quality and not relative intensity is in question, with all the curves crossing in the yellow at 0.59 μ at the value unity. The process of changing the basis of comparison is a serious one with most of the observations, because irregularities in the observed points are greatly magnified. The effect has been to make some of the points appear to lie on far from smooth curves.

Inspection of these values for sunlight shows a very fair agreement in their general position. It will be observed that the mean of all the measurements lies nearly long a curve with

its maxiumum near the middle of the spectrum. The true character of sunlight through the earths atmosphere is made more evident when we plot the energy curve of a black body at 5,000° absolute. This is the full line shown through the midst of the

Fig. 1.

observed points, and it is clear that this represents, about as closely as any line that could be drawn, the true average of the sunlight energy distribution as derived through spectrophotometric means. This distribution agrees closely in its maximum point and general character with the directly obtained energy distribution as found by Langley for high sun, and this agreement

serves as evidence that the observations and methods here employed are correct. The point of significance, which has been pointed out by Nichols, is that this energy curve has practically the same maximum of sensibility of the human eye, as determined by Koenig.

Taking up next measurements of clear blue sky, we have at our disposal measurements of Koettgen, against the Hefner; Vogel against petroleum (which in turn has been compared with the Hefner by Koettgen); Nichols and Franklin, against a "normally burning carbon lamp," which is here assumed to be a "4-watt" lamp, whose energy distribution is taken from figures by

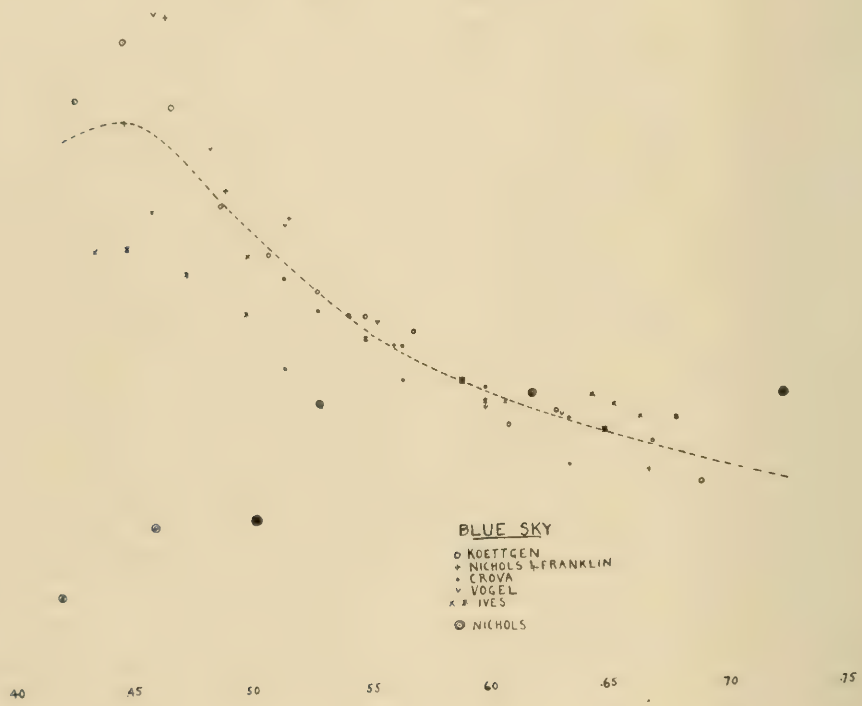

Fig. 2.

the writer, comparing it with acetylene; Crova, against a Carcel, assumed here as practically equivalent to the Hefner, and two sets of observations by the writer, one against acetylene, the other against the Hefner. The observations of Crova, it should be remarked, although numerous, are nearly all for only three points near the middle of the spectrum. His average value, from numerous observations, is well represented by the two sets here used, which were carried further toward red and blue. We should expect these clear sky observations

to be more scattered than those sunlight, partly because of the uncertainty in the true energy values of several of the comparison sources, and partly because there is more chance for varieties of clear blue sky, depending on altitude, than on clear noon sunlight. Nevertheless the general character of blue sky light is unmistakable, and, as we should expect, consists in an energy distribution much stronger in the shorter wave-lengths than is clear noon sunlight. When plotted in terms of energy, a common feature of nearly all the observations is a drop in the deep blue or violet. This has been noticed by Abney and by Nichols, but is not usually evident when the values are plotted in terms of the ordinary yellow artificial sources.

Before considering the color of the low sun, a few observations are available on those skies called cloudy or overcast. In Fig. 3 are plotted observations by Koettgen, Vogel, and Nichols

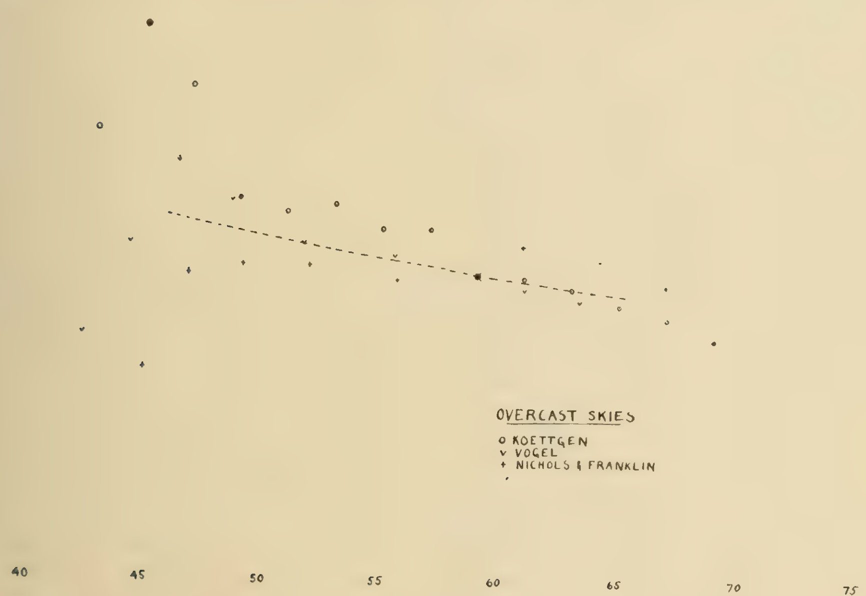

Fig. 3.

and Franklin, on such skies. These observations are comparatively few in number and show a range from near the clear sunlight value up toward the blue sky value. Overcast skies probably at times drop considerably below the clear sun value in the blue, since they owe their light principally to the sun, and this when low is considerably yellower than at noon.

Abney's observations on the change of color of sunlight by

passage through various thicknesses of the atmosphere are given diagrammatically in Fig. 4. These curves show that the light of the sun varies as much toward yellow for low elevations as does the sky toward blue.

By reducing all the available spectrophotometric determinations of sun and sky light to terms of radiated energy, it is therefore found that

1. Clear noon sunlight in summer corresponds closely to the energy determination of a black body at 5,000° absolute, this result agreeing with direct bolometric measurements.

2. Clear blue sky averages twice as much energy in the blue (λ 4,500) as does clear sunlight, for equal intensity in the yellow (λ 5,900).

3. Cloudy skies vary from near clear blue to clear sun, and probably below the latter in the blue.

4. The light of the sun at low altitudes shows a deficiency in blue similar to the excess in blue of the clear sky.

The evidence from spectrophotometric results indicates the probable correctness of the *a priori* reasoning that clear noon sun is a mean daylight, the blue light of the sky representing the extent of variation from this mean on one side, the color of the low sun the other extreme, clouds and mist varying between these extremes depending on their relative illumination by sky and sun.

We are now in a position to discuss the choice of an "average" daylight between those extremes. Where should it be chosen? Perhaps by making a large number of measurements extending over a long period we could obtain a mean which would be a reliable average. But even if we had many measurements our value would depend on how we weighted the observations. For instance should we consider sunlight or skylight as most typically "daylight?" Should we give the more intense light near noon more weight in forming an average than the fainter light of morning and evening?

It would seem to the writer that the best way to reach an acceptable value for "average daylight" is to take advantage of the coincidence which has been noted between the maximum of sensibility of the eye and the maximum of the sun's energy as it reaches us through the atmosphere. If we grant that this

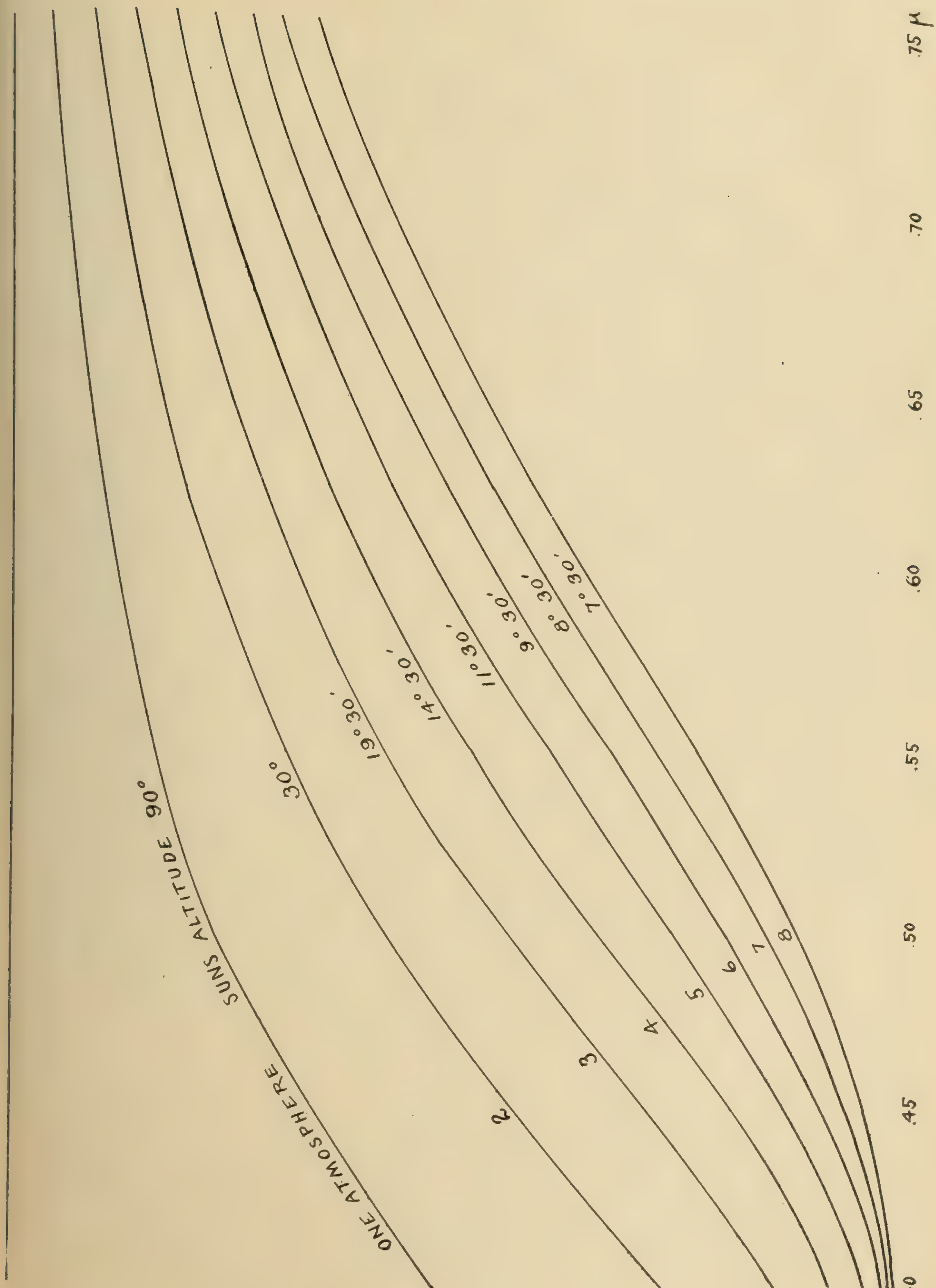
.75 μ
.70
.65
.60
.55
.50
.45
.40
ONE ATMOSPHERE
SUNS ALTITUDE 90°
30°
19° 30'
14° 30'
11° 30'
9° 30'
8° 30'
7° 30'
2
3
4
5
6
7
8

Fig. 4.

is not a mere coincidence, but a result of adaptation, we have a criterion for average daylight which is more exact than could be obtained by any series of daylight measurements, however, large. Since this adaptation exists, the inference is that the most probable average daylight is that daylight whose spectral maximum falls at the maximum of visual sensibility. In other words, the most efficient daylight is the average. As we have seen this corresponds to clear noon summer sunlight (in temperate latitudes, where the measurements quoted were made) which in turn agrees closely with the visible radiation of a black body at 5,000° absolute.

Further discussion of this value for "average daylight" will be deferred until the results obtained from color mixture measurements are considered.

Measurements of various illuminants have been made by the writer, using the Ives colorimeter. Instruments of this—the color mixture—type have certain advantages in measuring illuminants. An actual match is made, thus eliminating errors due to changes occurring during measurement, and further, some spectral distributions which are very difficult of measurement by the spectrophotometer present no difficulties in mixture instruments. On the other hand, like the eye, they give no direct information as to the spectral complexity of the measured source. The results of that investigation are given in terms of the quantity of red, green and blue necessary to be mixed to imitate the color of the illuminant. The standard of reference is an average daylight obtained by numerous measurements of sky illumination, as received through a west window on a white surface. In these measurements neither zenith blue skies nor direct sunlight (high or low) are included, so that while the extremes represented in the cited spectrophotometric values are absent, the average might be expected to be of the same order of magnitude as the spectrophotometric "average daylight."

As to the colorimeter results are obtained they are not directly comparable with spectrophotometer values. But, as stated by the writer in presenting the original measurements, the two kinds of measurements should be reducible to a common measure, namely, proportions of the primary red, green and blue sensations. The red, green and blue of the colorimeter are a par-

ticular red, green and blue; another selection of primaries (red, green and blue of slightly different spectral position) would yield different numerical values. If, however, we know the amounts of the primary red, green and blue sensations represented by each of the instrument primaries, we can transform the results into sensation values. All color mixture results should thus reduce to the same absolute figures. Similarly, knowing the sensation values at each point in the spectrum it should be possible to express spectrophotometer measurements in sensations. The two sets of measurements of the same lights against the same standard should therefore check. or conversely, having measurements of the same sources against two standards, we should be able to compare those two standards.

To reduce the colorimeter screens to primary sensation values two sets of sensation curves were available, namely those of Abney, and of Koenig as modified by Exner. These differ considerably, and in order to determine which appeared best to fit the colorimeter conditions a rather lengthy investigation has been carried out. This consisted in preparing a number of color screens of various hues and purities, measuring them on the spectrophotometer and determining their sensation values from the two sets of sensation curves. Similar measurements were made on the colorimeter screens. Then the color screens were measured with the colorimeter, by sunlight; and, by using the two different values for the colorimeter screens, the sensation values were derived. These were then compared with the sensation values obtained through the spectrophotometer. It was found beyond question that the sensation curves as determined by Koenig were a much nearer approach to the truth than those by Abney. Close agreement was found between the sensation values derived through the spectrophotometer and through the colorimeter with the Koenig values. Certain discrepancies remain, partly no doubt instrumental, others due to changes which take place in the sensation curves when the working illumination is greatly altered from that at which the curves were determined. It is therefore now possible to transfer the colorimeter measurements to primary sensation values with assurance that the results are not far from correct.

Using sunlight illumination, the colorimeter screens have the following sensation values.

	Red sens.	Green sens.	Blue sens.
Red screen	40.6	11.5	0.0
Green screen	50.0	86.6	12.7
Blue screen	9.4	1.9	87.3
	100.0	100.0	100.0

Using a tungsten lamp as the source behind the colored glasses of the colorimeter, a slight shift of hue takes place. In the instrument used, a faint band of green transmission in the blue screen (removed in later instruments) caused a further change of hue in the blue screen. This makes the sensation values of the screens in the instrument quoted:

	Red sens.	Green sens.	Blue sens.
Red screen	37.0	10.8	0.0
Green screen	45.7	76.7	7.1
Blue screen	17.3	12.4	92.9
	100.0	100.0	100.0

Using these values we are in a position to compare the average daylight of the colorimeter measurements with the average daylight which our reasoning above would indicate probable from spectrophotometric values and physiological considerations. A tungsten lamp at 1.58 w.p.s.c. was measured against acetylene with the spectrophotometer. Using as "white" the radiation curve of the black body at 5,000° absolute, the color sensation values for this lamp were derived from Koenig's sensation curves. These were, expressed so that their sum 100,

Red sens.	Green sens.	Blue sens.
47.9	41.1	11.0

The colorimeter readings on the same lamp, in terms of "average daylight," as preserved by measurements on certain incandescent lamps, were

Red	Green	Blue
61.4	31.7	6 9

These reduced to sensations by the use of the figures given above yield

Red sens.	Green sens.	Blue sens.
48.7	40.5	10.9

In short we find the average daylight of the colorimeter measurements to be practically identical with the average day-

light we found reason to believe probably correct from the spectrophotometric measurements, and by consideration of the sensibility curve of the eye. This agreement is indeed better than could be reasonably expected, since the colorimeter standard was not a weighted mean, and as stated above, did not include the extremes of daylight, zenith, blue sky, and low sun. There should have been agreement as to the order of magnitude, but a bluer or yellower hue for the colorimeter standard would not have been surprising.

Now although this very satisfactory agreement exists between the color mixture values and the spectrophotometer values quoted, there are some measurements by Prof. E. L. Nichols on the zenith sky, from which he has derived an "average daylight" in terms of the acetylene flame. These constitute probably the largest series of such measurements so far made and were highly instructive in calling attention to the great difference between day and artificial light colors. As was forecasted by the present writer in the original presentation of the colorimeter measurements, Prof. Nichols' values agree neither with these nor with the spectrophotometric results of other observers. The amount of the discrepancy is shown in Fig. 1, where Nichols' "average daylight" is shown on the same scale as the other observations. It will be seen that it corresponds to a daylight much yellower than the clear sunlight of the observers quoted, and exceedingly yellow as compared with their blue skies, corresponding in fact to a low sun. Were this a true average daylight, it would mean that the maximum of energy radiation in daylight lies at the extreme red limit of the visible spectrum, and is therefore very far from the maximum of sensibility of the eye. This is a conclusion which should be accepted only after very thorough proof.

There are various possible explanations of this difference. In view of the large number of measurements included in the set it might happen that the straight mean taken gave too much weight to cloudy skies illuminated by the low sun. This explanation is, however, hardly tenable, for if we take the bluest zenith sky measured by Nichols, "at sea," plated in Fig. 2, we see that it is not only very much less blue than any measured by other observers,—only about one-eighth as much energy in the

extreme blue as the average of these,—but much less blue than their clear values. This would mean that a clear blue sky could be much yellower than clear sunlight. It would seem therefore that Nichols' values are all too small in the blue. Variations in the quality of the acetylene flame might account for some of this difference but these variations have not been observed to be greater than a few per cent. at the ends of the spectrum. The true explanation probably lies in some instrumental or observational errors, such as the presence of scattered light in the spectrophotometer, which would cause the comparison source and measured light to appear nearer alike.[1]

Rejecting therefore the "average daylight" of Nichols, we have the evidence from the spectrophotometric observations, from color mixture measurements, and from the sensibility of the eye, that "average daylight" corresponds closely to the light of a black body at a certain temperature. This black body temperature is that at which the maximum of energy radiation corresponds to the maximum of sensibility of the eye, in other words, the black body whose visible radiation is the most efficient. This temperature is about 5,000° absolute. The fact that the eye permits large variations in the hue of a light while still calling it "white" warrants us in making this definition interchangeably that of "average daylight" or "white light."

It may be noted in passing that the efficiency of this black body as a light producer is within two or three per cent. of that of the most efficient possible black body, which as the writer has shown in a recent paper[2] is probably about 6,000° absolute. The fact that the higher temperature more of the total energy is shifted into the visible spectrum accounts for the fact that the most efficient black body is not the one whose maximum of radiation corresponds exactly to the maximum of visual sensibility, and makes clear the reason for the word "visible" in our definition "the black body whose visible radia-

[1] In a letter to the writer in regard to the discrepancy between his measurements and those here quoted, Prof. Nichols says "A likely source of error is to be found in the presence of stray light in the spectrum, as the measurements of the sky which I made were not primarily intended for this purpose of determining the relation between its spectrum and that of acetylene. . . . Many of the measurements were made out of doors under conditions in which the absolute screening away of daylight from the comparison spectrum with the apparatus which I had was impossible."

[2] See Illuminating Engineering Society, Philadelphia Section, January, 1910.

tion is most efficient." It is not beyond possibility that further knowledge of the sensibility of the eye and of black body radiation will show that the error would be negligible, if indeed any exists, if we adopted as the definition of white light simply "the light of a black body at its highest efficiency."

The standard of white or daylight being established we are in a position to find the place of artificial illuminants with respect to it. We may express the color relationship of these to white either by spectrophotometric measurements or in terms of the three primary sensations. These latter may be obtained from the spectrophotometric data by applying Koenig's sensation curves, or, because of the coincidence of the colorimeter standard with the standard here derived, the sensation values may be obtained, as indicated above, from the colorimeter values, with a fair degree of agreement between the two. In certain cases, where the illuminants have discontinuous spectra, measurement with the spectrophotometer is practically impossible, and has little meaning when obtained. Such are the flame arc, the mercury arc, the Moore tube.

In the appended table are given spectrophotometric data on a number of illuminants, and color values expressed in terms of color sensations, red, green, and blue. The spectrophotometric figures are from measurements made by the writer at the Bureau of Standards for the Union Carbide Sales Co., and used here by their permission. The standard of comparison was an acetylene flame (the center portion of the flame from a foot Von Schwartz burner), and the values for blue sky for clear sun obtained in that investigation have been incorporated with the others used to obtain the average values of these. The values at the different wave lengths are expressed in terms of energy, as discussed above, the acetylene flame being assumed equivalent in the visible region to a black body at 2,330° absolute as calculated from the Wien-Planck formula $E = \dfrac{\lambda^{-5}}{e^{\frac{14900}{\lambda T}} - 1}$. The Hefner figures are also black body values for a temperature of 1,830°; the white or daylight, for a temperature of 5,000°. The sensation values are given in such manner that the sum

of the three values equals unity. Where both spectrophotometer and colorimeter values exist the sensations as derived from each are given, the colorimeter values in italics, from which the degree of agreement from the two methods may be seen. It must be borne in mind that the actual sources measured were not usually the same, so that some differences are to be expected on this score, others are due to the difficulties inherent in obtaining figures by two entirely different methods, in the present state of the process of measuring color.

In Fig. 5 are plotted the spectrophotometric values as curves,

Fig. 5.

crossing at 0.59 μ according to the usual convention where quality and not relative total intensity is in question. In Fig. 6 are given the sensation values (mean values from the two methods) in the form of a color triangle, at the center of which is white, while the red, green and blue sensations lie at the corners.

In this the distance of a source from the center is a measure of its approximation to white. The natural illuminants are represented with circles around the position giving points.

A few words of comment will not be out of place. From the spectrophotometric curves it is clear that the majority of artificial illuminants vary from white in the direction of less

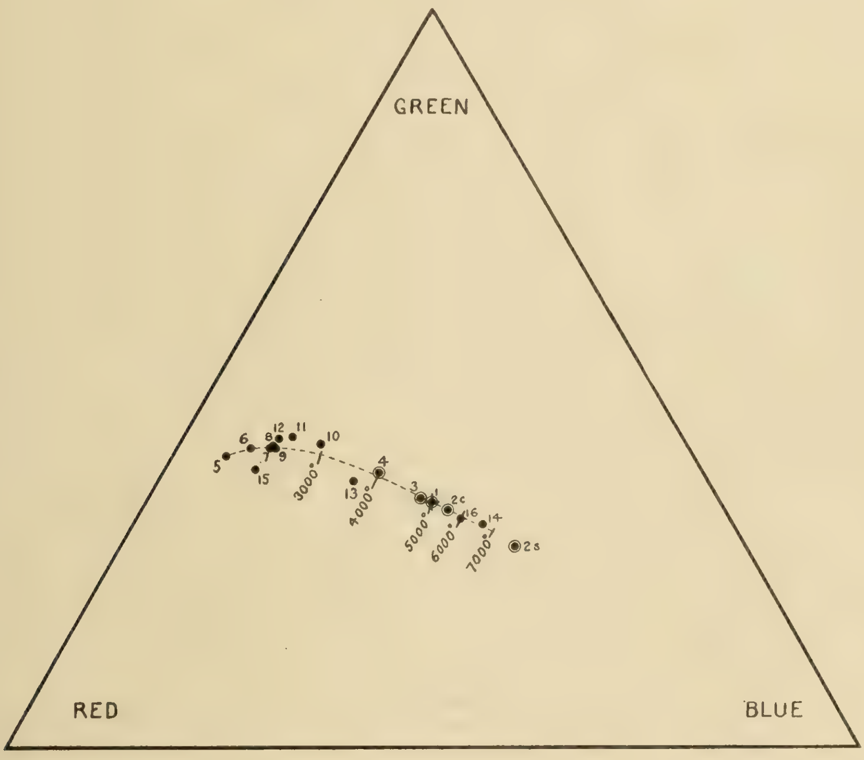

Fig. 6.

blue and more red. They are in fact nearly all yellow. The color triangle representation shows the same characteristic. Many of the more usual illuminants lie far from the center in the direction of yellow, or away from the blue. To this there are several exceptions. The carbon arc, the mercury arc, and the carbon dioxide vacuum tube are not farther from the center than are some of the varieties of daylight. The carbon arc is by far the nearest white of the incandescent solid illuminants, although its hue is decidedly toward yellow. As to the mercury arc, it should be carefully borne in mind that the figures here give the color of the light itself, or the color of a white sur-

face illuminated by it. The fact that there is no red in this light is only apparent upon viewing objects under its illumination. The resultant green effect gives a very general impression that the light itself is green, although it is not. Of all the artificial illuminants the Moore carbon dioxide tube lies nearest to the average daylight here adopted. From the color triangle it is seen that it lies between the average of blue skies measured by the colorimeter and by the spectrophotometer. It is, therefore, somewhat bluer than clear sunlight (which we found reasons for believing an average daylight) but not as blue as the bluest blue skies. Owing to the nearly continuous character of its spectrum, its color value as an illuminant as well as its actual color are properly represented by its position in the triangle.

A dotted line drawn in the triangle gives the color of the black body, or an incandescent solid for temperatures up to 7,000° absolute. Along this curve lie nearly all the artificial illuminants. Those whose radiation in the visible spectrum is selective, or different from black body radiation of course lie away from it. Thus the carbon arc is to one side because of the blue or violet of the arc itself; the Welsbachs lie above because of their larger amount of green; the flame arc, whose light is only very little due to the incandescence of a solid, lies far from this curve; the carbon dioxide tube coincides closely with the light of a black body at 6,000° absolute.

A point of interest, which can only be mentioned here but would appear to bear some study, is this,—the eye, being accustomed to light produced by incandescent solids, seems to notice less, and to take less offence, at illuminants varying from white as incandescent solids do than if they vary in other ways. We quickly feel the green tinge of a Welsbach or the ruddy hue of the flaming arc, but a color change quite as great as from one of these to the incandescent solid, if it consists in changing from one incandescent solid color to another, does not seem to give an impression of a prevailing color tinge. If this phenomenon of sensation is real it indicates that one criterion for a satisfactory illuminant would be that it should lie close to or preferably upon the black body color curve. To this criterion should, of course, be joined the one that has been made evident by consideration of the mercury arc, namely that its spectrum should

be practically continuous in order that its color shall truly represent its effect as an illuminant.

With these figures the purpose of the present paper is fulfilled. A standard of daylight color value has been obtained, and with this most of the artificial illuminants in common use have been compared, using the two methods of color measurement by which data have been obtained. The result has been to show the extent of the color difference existing between that daylight to which the eye is best adapted, and the commonest illuminants. The many variables in the problem have made necessary in places the exercise of judgment rather than the direct use of measurements, the discarding of some values, and the weighting of others by consideration of other than strictly physical factors. It is believed, however, that the results are trustworthy to a degree such that they may be accepted as representing substantially the facts. Upon them it should be possible for the physiologist or other investigator interested in the specific effects of color in illuminants to base his work.

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Source	Energy value by wave-lengths															Sensation values		
	.41	.43	.45	.47	.49	.51	.53	.55	.57	.59	.61	.63	.65	.67	.69μ	Red	Green	Blue
1 Black body at 5000° abs.	72.0	79.0	84.3	91.0	92.5	96.0	98.0	99.0	100.0	100.0	100.0	98.5	97.1	95.5	93.5	33.3	33.3	33.3
2 Blue sky S	177.0	185.0	187.0	180.0	162.0	146.0	132.0	120.0	108.0	100.0	93.0	87.0	82.0	77.0	72.5	26.8	27.2	46.0
C																32.0	32.2	35.8
3 Overcast sky																34.6	33.9	31.5
4 Afternoon sun																37.7	37.3	25.0
5 Hefner	1.9	3.5	6.0	10.5	16.3	25.5	37.5	53.2	74.5	100.0	130.0	168.0	210.0	260.0	320.0	53.5	40.3	6.2
																55.0	38.8	6.2
6 3.1 wpc. carbon lamp	4.0	7.0	12.0	18.0	25.5	34.5	47.0	62.0	79.0	100.0	123.0	148.0	176.0	204.0	234.0	50.9	40.6	8.5
																51.3	40.4	8.3
7 Acetylene	5.5	9.6	15.0	21.9	30.3	40.0	52.0	66.5	82.0	100.0	118.5	139.0	160.0	182.0	205.0	48.1	41.0	10.9
																49.1	40.5	10.5
8 Tungsten 1.25 wpc	6.5	10.2	16.0	22.8	31.5	40.5	52.5	66.5	82.0	100.0	118.5	138.0	158.0	179.0	201.0	47.9	41.1	11.0
																48.7	40.5	10.9
9 Nernst																49.2	40.7	11.1
10 Welsbach, ¼ % cerium																42.5	40.8	16.7
11 " ¾ % "			17.5	26.4	38.3	51.0	64.0	78.0	90.0	100.0	107.0	111.0	114.0	119.0	120.0	45.2	42.0	12.8
																45.5	42.0	12.5
12 " 1¼ % "																47.2	41.8	11.0
13 D. C. arc		21.8	29.0	37.0	45.5	55.0	65.5	76.0	88.0	100.0	113.5	127.0	142.0	156.0	170.0	41.0	36.3	22.7
14 Mercury arc																29.0	30.3	40.7
15 Yellow flame arc																52.0	37.5	10.5
16 Moore carbon dioxide tube																31.3	31.0	37.7

A paper presented at a meeting of the New York Section of the Illuminating Engineering Society, March 17, 1910.

A STANDARD FOR COLOR VALUES—THE WHITE MOORE LIGHT.

BY D. MCFARLAN MOORE.

That the problem of *how* to obtain an artificial light entirely suitable for matching all colors at night has been solved for some time past is just beginning to receive wide recognition. The passage of an electric current through rarefied carbon dioxide in a glass tube produces a form of light the spectrum of which causes all objects illuminated by it to have the identical shades of color they would possess under average diffused daylight. Again I assert that so far as the reproduction of daylight color values are concerned, nothing further need be desired; and for this purpose the Moore CO_2 light should be promptly adopted by all suitable scientific societies as the standard.

The hope of obtaining any other standard source of color than from some form of light is dismissed as wholly impracticable and unscientific. Secondary standards of color are common; for example, in the paint industry, but accurate reproduction is impossible. Light is the source of color. It is composed of ether waves of different lengths which cause the retina to have different sensations. Therefore, a standard source of colors should be a form of light. In other words, every color of an object we wish to see properly must be illuminated by a source of light containing wave-lengths corresponding to every color.

Since it is believed that the final culmination in the evolution of artificial light production will result in an almost universal use of light sources having daylight color values, it is important to record the various steps in this direction up to the present time. Carefully tracing the evolution of all forms of light from remote ages down to the present time, particularly as regards color, clearly proves that electric light from carbonic acid gas is a natural sequence and that the times are now ripe for it. Ancient history indicates that man has always attempted to invade the domain of night.

Although the Greeks and Romans were far advanced in many branches of science, nevertheless their reddish flickering torches and crude yellow smoking oil lamps were the limits of their attainments in artificial illumination, as indicated by Pliny and Homer.

At Cambridge University, Sir Isaac Newton first revealed the true nature of color. It is to be noticed that as time has advanced the various forms of light have become whiter. Indeed to-day the procession is still with us, and we can easily pass from the

Fig. 1.

light of the open fire place to the candle, to the ordinary oil lamp, to the gas lamp, to the carbon incandescent, to the Welsbach, to the Nernst, to the tungsten, to the acetylene, to the arc lamp, and with some assurance of finality, as regards reproducing the colors of daylight—the Moore vacuum tube.

In 1894, after constructing a number of new forms of what I designated as "vacuum tubes," and filling them with rarefied CO_2, I made the claim that in my experimental dark room objects had more nearly their daylight appearance than under any other light. I repeated this claim for the color qualities of my white tubes in a paper presented to the A. I. E. E., April 22, 1896, and

illuminated by means of several dozen 7-foot vacuum tubes the entire meeting hall as shown in Fig. 1. It was the first lighting

Fig. 2.

ever accomplished with proper color values. The following month at the first New York Electrical Show at the Grand Central Palace my claims were corroborated by spectroscopic tests

of Dr. W. H. Birchmore, who also stated that the spectrum of these special electrodeless tubes should be called continuous.

Examinations with like results were also made by Mr. Joseph Wetzler, Mr. Nelson W. Perry, and Prof. W. A. Anthony. In 1898 many thousands witnessed the lighting of the "Moore Chapel" (Fig. 2) at Madison Square Garden, by means of vacuum tubes operated from a rotating vacuum break. These curved electrodeless 8-foot tubes had an intensity of only ¼ candle-power per foot. Their life and white

Fig. 3.

color was entirely dependent upon the fact that previous to the rarefaction of the air within them they had been rinsed with a poor quality of wood alcohol, the organic residue of which, when acted upon by the electric current, gave off CO_2. Similar tubes were lighted for the first time by dynamic currents direct (that is without any form of make and break whatever) on June 1, 1899, in a laboratory of the author (Fig. 3). In a report on this form of tube in June, 1901, Dr. A. E. Kennelly stated that

The color of the light resembled that of diffused daylight, and there was a remarkable freedom from shadows, owing to the wide distribution of the tube over the 760 square feet of floor space. It was easy to read fine print in any part of the room and the effect of the light was both subdued and pleasant. Daylight color values seem to be well reproduced by this light. Where a soft uniform illumination is desired in close imitation of diffused daylight, the Moore system has a definite field of usefulness which at the present time neither the incandescent lamps nor the gas lamp, nor the arc lamp can fill.

To permit of increasing the intensity per foot to 3 c.p. the first tube 100 feet long was constructed January, 1902, in the Newark

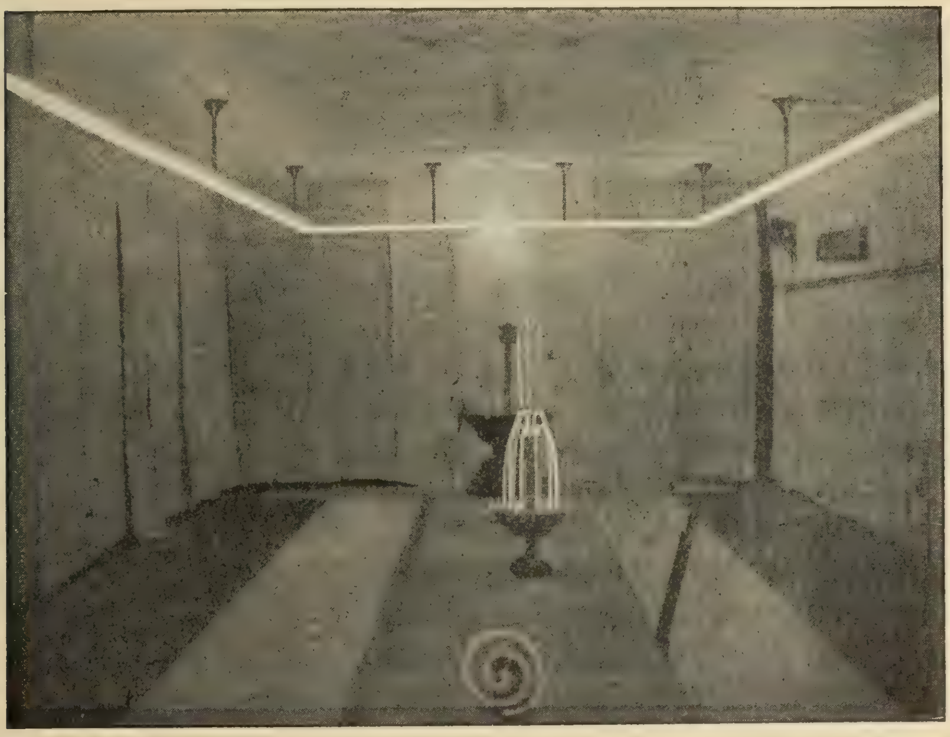


Fig. 4.

laboratory of the author (Fig. 4). In a report on this pioneer tube in June, 1902, Dr. Kennelly stated,—

The illumination was pleasing,—the light is soft and white. Daylight color values seem to be well preserved by it so that objects appeared in their natural daylight colors.

The first installation of the Moore loop tube system outside of the laboratory was at 50 Broadway, N. Y., and from a report on this tube dated August 9, 1902, by Mr. Joseph Wetzler, is quoted:

The light given out is of a soft, white character, an almost exact equivalent of sunlight to the eye, and colors undergo no discernible change as compared with their appearance under sunlight. I made a test to determine this latter property, so valuable for all interior illuminants. Indeed the room at 50 Broadway has the appearance of being illuminated by north light on a bright day.

But at this intensity the CO_2 derived from the wood alcohol impurities had a life as a gaseous conductor of only a comparatively few hours and hundreds of other organic liquids and solids and other chemicals were tried. By far the best sub-

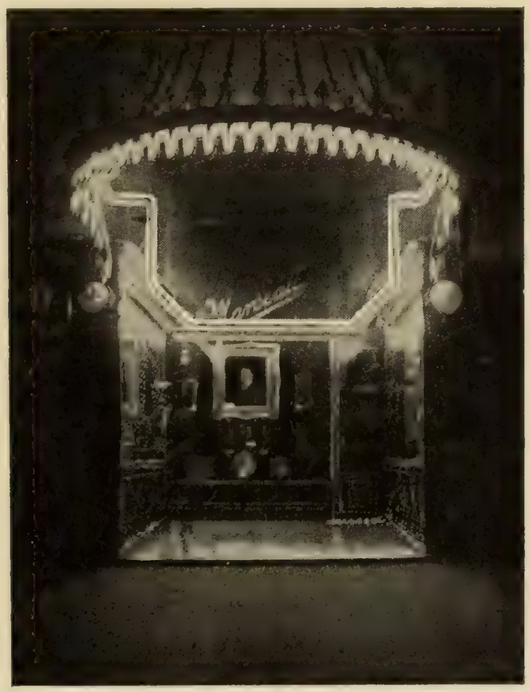


Fig. 5.

stance found for furnishing the CO_2 gaseous conductor was graphitic acid which was dusted, in the form of a brown powder, on the inner surface of the large external cap electrodes connected to the special generator of about 100,000 alternations. A tube of this kind installed at 258 Fifth Avenue, N. Y., (Fig. 5) in 1903 became the first example of commercial lighting by the use of a vacuum tube.

In the report on the first year's operation of this and other Moore tubes, Mr. Max Loewenthal in April, 1905, stated that:

It is used to illuminate high grade photographs and oil paintings.

which appear under it exactly as they do in daylight. This tube substantially proves beyond question the claim made by Mr. Moore for this light—viz., that it deserves the name of "Moore Electric Daylight."

It is still in operation, although its color has now changed from white to a nitrogen yellow.

The long tube installed in 1904 at No. 200 Market Street, Newark, was the first to operate directly from the alternating-current street mains, that is, without the necessity of a special generator, which was accomplished by using small internal

Fig. 6.

graphite electrodes with which as the gas source graphitic acid was not suitable, but rosolic acid after being slowly heated to a condition resembling burned sugar, did best. The current acting on the electrodes caused the CO_2 gas to be evolved as needed, but the tube was liable to soon become badly soiled and besides it was subject to atmospheric temperature variations.

In 1905 the long Moore light tube at 1381 Broadway, N. Y., (Fig. 6) had its carbon electrodes containing rosolic acid replaced with new electrodes without any chemical, but there was installed instead for supplying the necessary gaseous conductor to the tube, *a new automagnetic feed valve* and shortly after a tube similarly

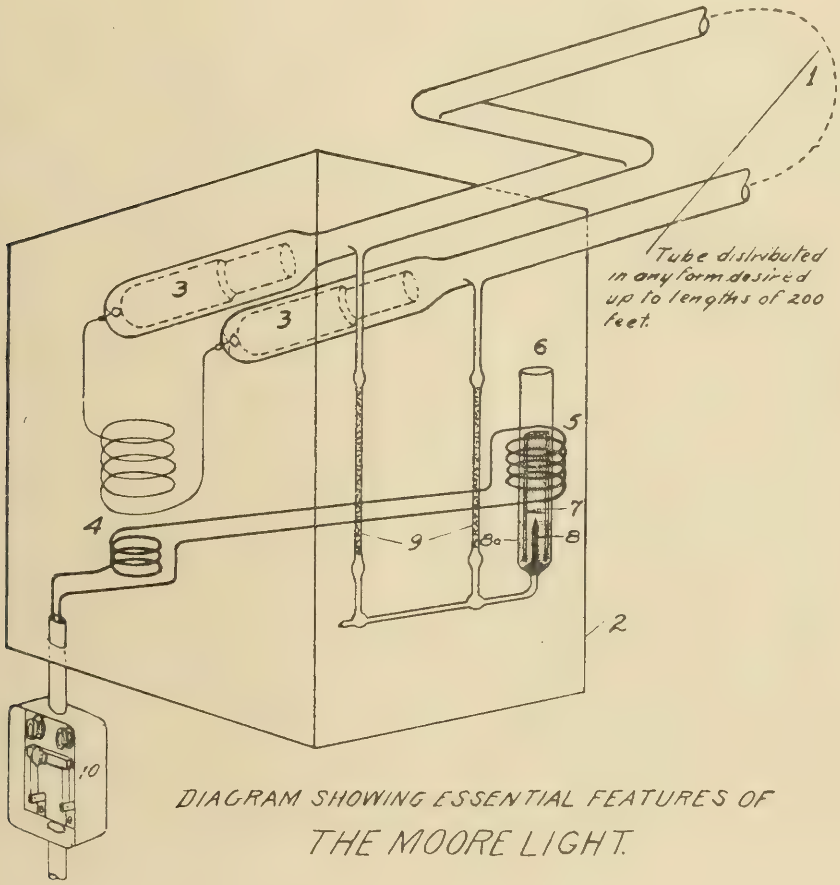
equipped with an electromagnetic feed valve was installed and is still in operation in the lobby of Madison Square Garden. Its gaseous conductor is nitrogen, not CO_2, but it is to be noted that the design of the Moore light tubes is such that if desired all kinds of gases can be used in them either singly or in combination, thereby making possible a wider variation in the color of the light than with almost any other illuminant known. That is, the color can be scientifically controlled over wide ranges. In the department store at 697 Broad Street, Newark, N. J.,

Fig. 7.

(Fig. 7) the Moore light tube is located over the ribbon counter, and since it is automatically fed with CO_2 gas it is the first instance of correct artificial color values being practically used in merchandising. The light of this tube was examined in 1906 by the research department of the *Illuminating Engineer*, which found that "as an approximation to sunlight, it is remarkably close." In a portrait studio which has been equipped with the white Moore light it is stated that artists working in water colors are enabled to work by the artificial light with exactly the same results as by daylight; and in a department store in which it has been installed, the salesmen state "it is equal to

daylight for the purpose of matching colors." And again, at a lecture before this Society in 1907, Prof. H. E. Clifford said:

I saw one white tube in operation and made some comparisons of color and I must confess that it seemed to me that matching was just as



1 - THE MOORE TUBE
2 - TERMINAL BOX.
3 - TERMINAL ELECTRODES.
4 - TRANSFORMER.
5 - FEED-VALVE COIL
6 - GLASS TUBE OF FEED VALVE.
7 - GLASS AND IRON WIRE DISPLACER.
8 - POROUS PLUG.
8a - MERCURY.
9 - SAND RESISTANCE TUBES.
10 - 220 VOLT, 60 CYCLE A.C. SUPPLY.

Fig. 8.

good under the white tubes as with daylight. With the white light we can match delicate lavenders, etc., and we can almost match colors at the red end of the spectrum as well.

Since the automatic feed valves above referred to at the present

time are a vital part of the standard white Moore light, it is essential that they be described.

Fig. 8 is a diagram of a standard terminal box for a Moore tube about 100 feet long. The Moore light is produced by a high voltage discharge through a gas under high vacuum. Note the transformer and the feed valve to the right which is connected by small glass tubes to the glass enclosed graphite terminals of the main lighting tube. The CO_2 at about 5 lb. pressure was formerly fed to the top of the feed valve from a tin tank about 6 in. in diameter and about 1 ft. high. Later, liquid CO_2 through a reducing pressure gauge was used, but at the present time the CO_2 is automatically generated by the tube itself as needed.

Fig. 9 shows the construction of this CO_2 generator and its method of connection to the top of the feed valve by what is called the chemical connector.

In Fig. 10 the curve Y X indicates the current characteristics of the feed valve action. It opens and closes continuously about once every minute when the current through the tube has become strong enough to lift the displacer and thereby expose the minute tip of the porous carbon plug. A small portion of any gas above it (CO_2 for example) is drawn down through the pores of the plug and into the lighting tube to be utilized as the gaseous conductor producing the white light. When the gas above the plug becomes rarefied, atmospheric pressure causes the hydrochloric acid to rise within the inner tube and come in contact with the marble chips or pressed lozenges of calcium carbonate. A very small quantity of CO_2 gas is immediately set free, which passes over to the vicinity of the porous plug and is ready when needed.

The experience of the clerks under the first tube installed over the ribbon counter was very satisfactory. They found that the light from the Moore tube was not only equal to, but preferable to that of day, so that the use of the Moore light was then suggested to the largest silk dyer in the world, located at Paterson, N. J. Their expert color matchers, who had been brought from Germany and Switzerland for this special work, were extremely skeptical when first informed that science could

furnish them with a light that was the equal of the best day-

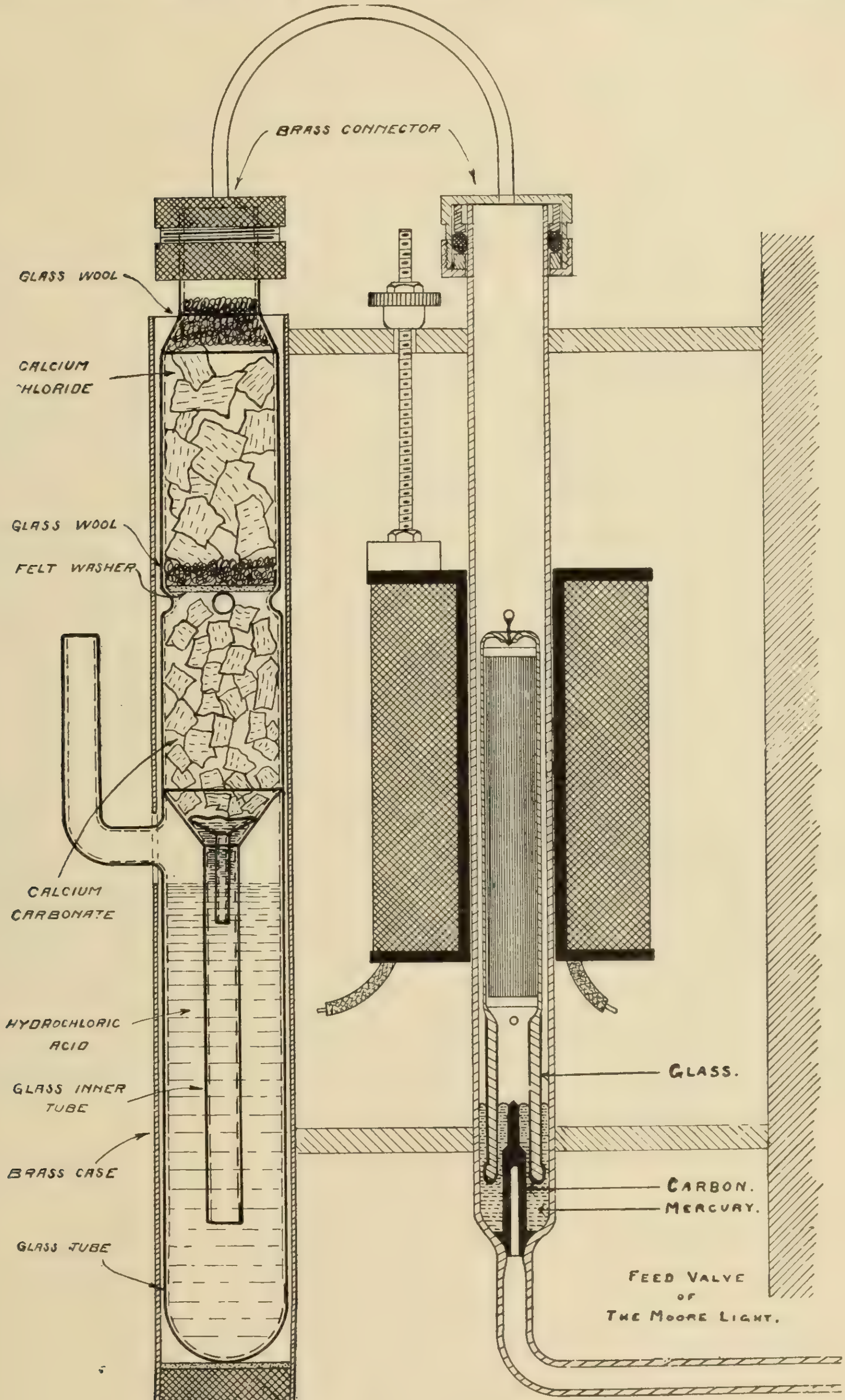


Fig. 9.

light, but which of course was always instantly available and absolutely uniform in quality. Upon being thoroughly con-

vinced after over a year's rigorous testing, the management agreed that there was most urgent necessity for such a standard light, and that it was now possible for the first time to manufacture with scientific accuracy all classes of colored goods.

Various forms of tubes have been installed in different parts of this large establishment, but comparatively recently a new building has been erected, which is 340 feet long by 250 feet wide. The major portion of this entire floor area is occupied by dye tanks. On one side of this building uniformly spaced,

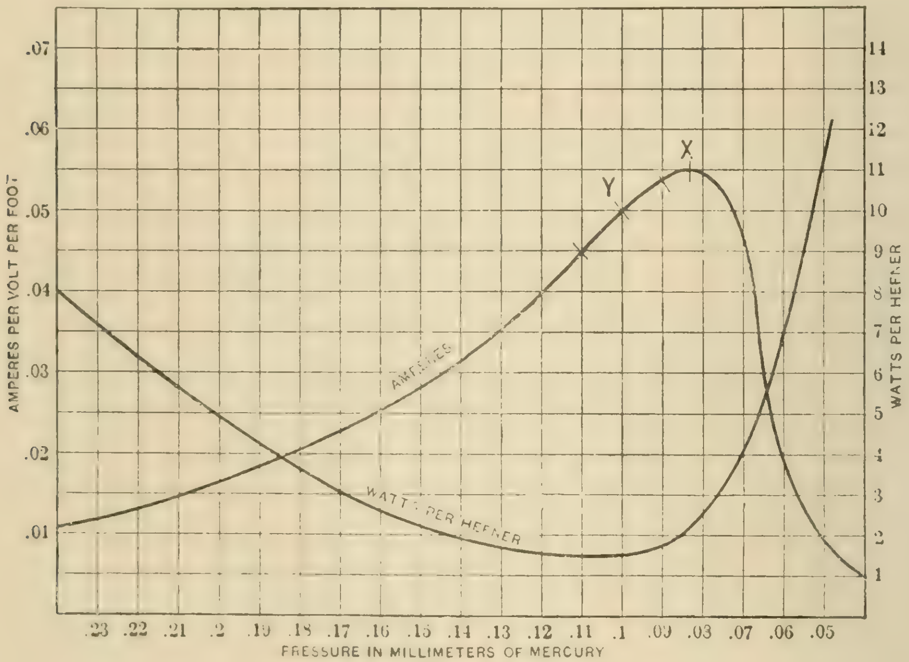


Fig. 10.

two color matching rooms have been located. When a workman thinks he has the skein of silk he is dipping in his vat dyed to its proper color, he carries it to the color matching room, where one of the head dyers intently compares it with the small sample of silk he has in his hand of the color they are endeavoring exactly to duplicate. Each of these color matching rooms is 14 feet long and 9 feet wide and 9 feet high. In all other instances the interiors of special color matching rooms have been painted white, but in the case of these two rooms the experiment is being tried of having their interior a dead black.

The results thus far are as good as obtained with white paint.

but of course to obtain a given number of foot-candles on the working plane requires about double the amount of electrical energy. On the ceiling of each room are placed two separate white light tubes, each of which is 60 feet long and 1.75 in. in diameter. The two tubes in each room are put upon different phases of the 220 volt, 60 cycle, alternating-current service available. This practically obviates the image effect which can be detected in the light from either Moore tubes or arc lamps on single-phase circuits.

A photograph of one of these color matching rooms is shown

Fig. 11.

in Fig. 11. Somewhat similar color rooms, as shown in Fig. 12, have been equipped for a very large number of textile concerns, so that the white tube light has now become a necessary adjunct to silk dyeing and other industries. Tubes of this design have a total length of 62 feet and the standard apparatus is suitable for 220 volts, 23 amperes, 60 cycle alternating current and consumes about 3 kw. when producing a light of an intensity of 11 hefners per foot. It enables first, the production

of a far more uniform quality of goods, and second the extension of the hours of labor to all night and in all kinds of weather. Heretofore on cloudy days and during the winter months after 3 or 4 o'clock, color matching was impossible and silk dyeing had to come to a standstill. Now with the "artificial daylight" the outside daylight conditions are not noticed. It was for these

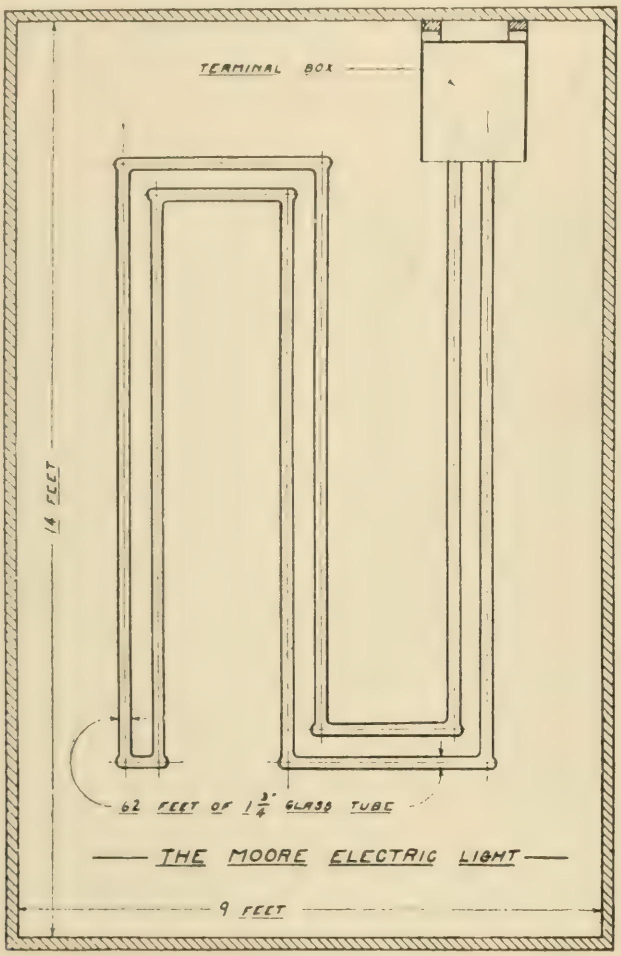


Fig. 12.

reasons that in June, 1906, in an address before the N. E. L. A. at Atlantic City, I first used the expression,—then seemingly impossible,—"better than daylight." From the above it will be noted that for one reason or another a large number of scientific men and engineers of high standing from both America and Europe have made investigations or reports on the white Moore light and in every case have pronounced its color qualities as most remarkable and approximating natural light.

In August, 1907, accurate and exhaustive spectroscopic tests were made by the corps of experts of the Siemans Schuckert Co. in Berlin under the direction of Prof. Utzinger. From carefully plotted curves he made the statement that the white Moore light did not differ from the "average daylight" they had decided upon by more than 3%. Of course these two curves were under certain conditions on certain days almost identical, but at times the carbon dioxide curve was slightly higher at the blue end of the spectrum, while at the red end of the spectrum it was slightly lower. Under these conditions the two spectrum curves crossed midway between the yellow and the green.

In a voluminous report dated October, 1907, after careful tests, Prof. J. A. Fleming in London stated:

Prior to the date of the inventions of Mr. Moore no one had achieved any such success by the employment of a gas rendered incandescent by an electric current as a means of lighting. Moreover he has provided us with the means of illumination which more completely than any other approximates to daylight in its uniform diffusion and power of revealing tinted surfaces of bodies in their natural or daylight colors, while possessing at the same time considerable actinic or photographic power. I have found that a Moore vacuum tube lamp filled with carbonic dioxide imitates daylight very perfectly in its color revealing qualities, so that it is possible to execute water color sketches, oil or porcelain painting or other artistic work as well by this light as by day.

At the Convention of this Society in October, 1908, Mr. Frederick E. Ives said:

It seems to me that the light of the carbonic dioxide tube comes nearer to daylight than that of any of the other artificial illuminants used in our tests. My impression of the carbon dioxide tube was that because of its steadiness and because the light was rich in blue, it was the most satisfactory source of artificial illumination for the comparison of colors of anything I had seen, but my impression was that it represented the color of a moderately blue sky.

And again at the New York meeting of November, 1908,—in referring to subsequent tests:

The tube was compared against the blue sky at zenith and against sunlight reflected from an opal glass. The light of the tube was less blue than the sky at zenith, but twice as blue (relatively to the red) as the sunlight reflected from the opal glass; and that corresponds to the estimate I gave at Philadelphia that the light of the tube corresponds to a moderately blue sky. The light from the carbon dioxide tube

would be incomparably better for matching colors than the Welsbach lamp, in fact there is nothing better. The light from an electric arc lamp is good but not an absolutely fixed standard like that of the carbon dioxide tube.

Mr. E. L. Elliott also said:

I believe Mr. Moore's contention that one could do no better in selecting a standard white light than to use his CO_2 tube. The light from it is something which can always be produced of invariable quality so far as color is concerned, and I think that the suggestion is a very important one.

In June, 1909, a white Moore light tube was installed in the U. S. Bureau of Standards in Washington, D. C., and subjected to a series of tests, resulting in the official report signed by Prof. E. B. Rosa, acting director, that its light

Contained relatively more blue than the light from the sky near the horizon, and very much less blue than the light from the zenith when the sky is clear. It follows from this that the Moore carbon dioxide tube would be found to contain the same proportion of blue to red as the light from the sky at some altitude between the horizon and the zenith when the sky is clear, the particular altitude depending upon how dry the atmosphere is at the time of the measurement. In other words, the carbon dioxide tube is nearly the average of the light from the clear sky, but as this varies from time to time, according to the clearness of the sky and the dryness of the atmosphere, it is impossible to give the value of average daylight in exact figures.

At the convention of this Society last fall, Dr. H. E. Ives stated that

It is perfectly safe to say that the Moore tube measured in the Post Office is very closely the color of the sky on a perfectly clear day at some point between the horizon and the zenith.

A report of tests dated December 17, 1909, by W. J. Dibdin, of Bradford, England, says:

The light produced by the carbonic acid vacuum was excellent for the differentiation of colors.

Fig. 13 shows a lumichromoscope as exhibited at the Philadelphia Electrical Show last month. Seven varieties of artificial illuminants were arranged simultaneously to illuminate different portions of the same lengths of colored ribbons. Practical results obtained from lumichromoscope tests are tabulated in Fig. 14. The first three columns show just how the various forms of light change each of the three primary colors, red, green, and blue.

Some of the changes are very marked. They can be divided

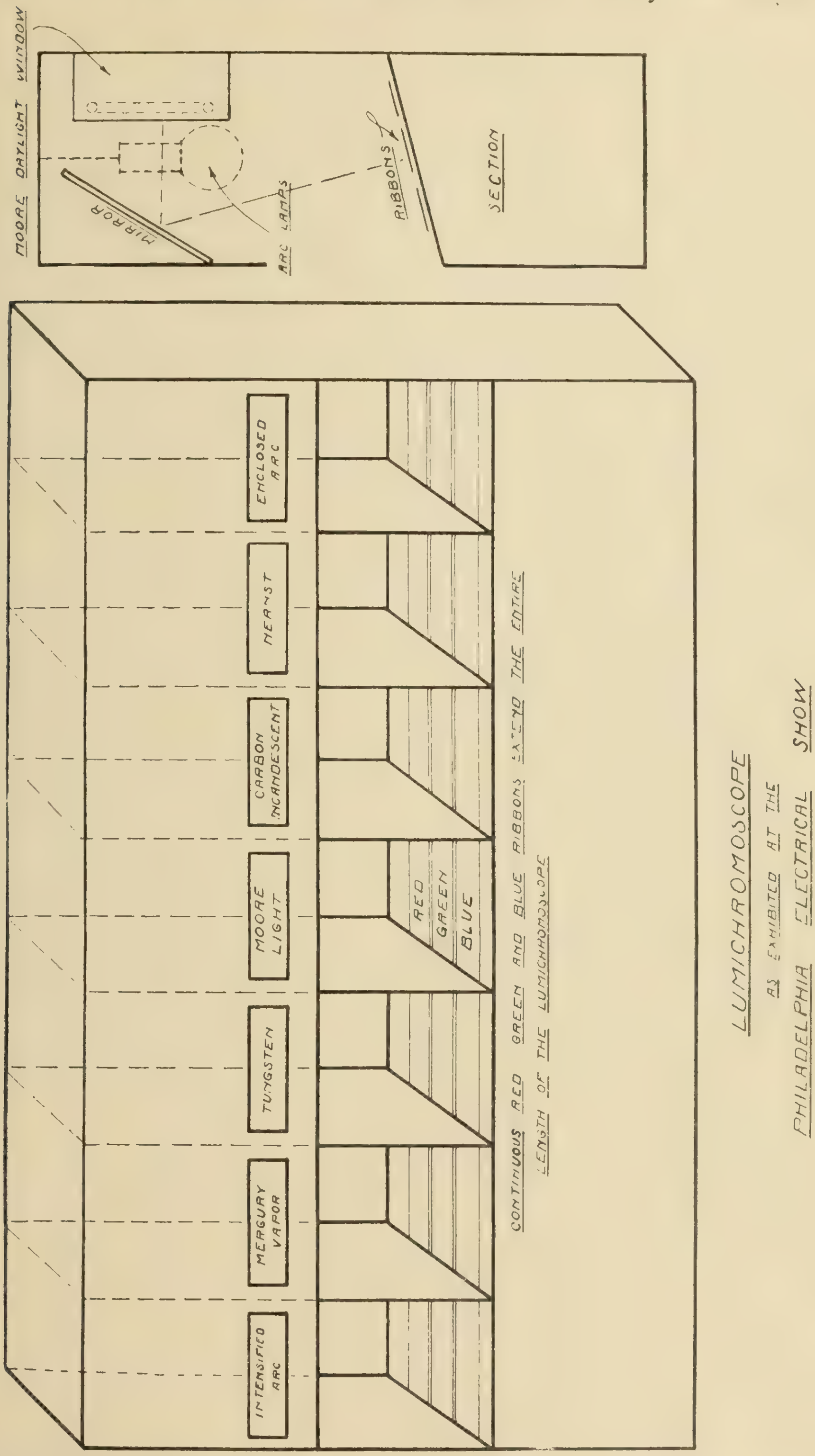


Fig. 13.

into two general classes, viz., first, changes of shades, and sec-

Fig. 14.

Kind of light.	Appearance.	Primary colors.			Brown.	Yellow.	Lavender.
		Red.	Green.	Blue.			
Average diffused daylight.	Bluish white or pure white.	A normal red as standard.	A normal green as standard.	A normal blue as standard.	Brown.	Yellow.	Lavender.
The white Moore light.	Pure white	A normal red as standard.	A normal green as standard.	A normal blue as standard.	Brown.	Yellow.	Lavender.
Intensified arc.	Bluish white.	Changed to a lighter red.	Green.	Changed to a lighter blue.	Brown.	Changed to a lighter yellow.	Changed to a lighter lavender.
Enclosed arc.	Bluish white.	Changed to a considerably lighter red.	Green.	Changed to a much lighter blue.	Changed to a lighter brown.	Changed to a lighter yellow.	Changed to a lighter lavender.
Tungsten.	Yellow white.	Changed to a good many shades lighter.	Changed to a yellowish green.	Changed to a dark purple.	Changed to a reddish brown.	Changed to an orange.	Changed to a pink.
Nernst.	Deep lemon-yellow.	Changed to yellowish red and a little lighter.	Changed to a yellowish green.	Changed to a little darker blue.	Changed to a golden brown & many shades lighter.	Changed to a golden yellow and lighter.	Changed to a light pink.
Carbon incandescent.	Orange-yellow.	Changed to a good many shades lighter.	Changed to a yellowish green.	Changed to a dark purple.	Changed to a reddish brown.	Changed to a deep orange	Changed to a pink.
Hewitt mercury vapor.	Blue-green.	Changed to a very dark red—nearly black.	Changed to a little lighter green.	Changed to a good many shades lighter blue.	Changed to a distinct green.	Changed to a greenish yellow.	Changed to a bluish gray.
Welsbach	Greenish yellow.	Changed to a darker red.	Changed to a slightly yellowish green.	Changed to a navy blue.	Changed to a little darker brown.	Changed to a light orange.	Changed to a faded lavender.
Fish tail gas	Pale yellow.	Changed to a little lighter red.	Changed to a yellowish green.	Changed to a deeper navy blue.	Changed to many shades darker brown.	Changed to orange.	Changed to old rose.

ond, changes of color. In the practical work of the textile industry both of these classes or changes are very important. However, the great mass of the business is not confined to working with the three primary colors, but has to do with the odd shades of colors of every conceivable hue, thus making uniform results far more complex, and emphasizing the importance to the art of the great improvement of having an absolutely fixed standard as the basis for all color comparison. White and creams can be easily distinguished, as well as the close shades of blue and black. In fact the white Moore light does not need to apologize for its lack of ability accurately to determine exact shades of any and every color.

The information contained in this table is of the kind that has proved very interesting and valuable to the practical worker in colors. It shows why each of the forms of light, except the white Moore light, is unable to give practical service in industries dependent on color. All of the older forms of illuminants are chiefly weak in the blue end of the spectrum. This becomes more pronounced as the temperature of the source is lower, from the candle and oil lamp up to the Welsbach mantle.

Some of the new extremely high temperature filaments and glowers approach nearer to proper color values, especially when new, than did their more moderately heated predecessors.

The Hewitt mercury vapor light is included in this table not because of any thought of its being seriously considered as suitable for color matching, but simply to show to what extremes colors are changed under lights which have spectrums which are almost monochromatic. It changes the red almost to black, and brown to a distinct green.

An ordinary gas flame changes yellow and orange and lavender to old rose. The carbon incandescent lamp changes blue to purple, yellow to orange, and lavender to pink. The Nernst lamp changes green to a yellowish green, and lavender to a light pink.

The tungsten lamp also changes green to a yellowish green, blue to purple, yellow to orange, and lavender to pink.

The arc lamps cause considerable change in shades of color but do not materially change the kind of color. All forms of arc

lamps up to the present time have failed fully to meet the exacting requirements of the large practical dyers. Also due to the feeding of the arc neither the spectrum or the intensity is perfectly constant.

It is thus seen that having adopted a standard, how very satisfactory it will be to express the color of all other forms of light in terms of it. The great variety in the color of the many new forms of light make the necessity for such a standard far more imperative now than a few years ago, when all forms of light had almost the same yellow color. After a standard has been adopted and we designate the color of a certain light as yellowish-white, we will mean as compared to the standard white light.

In addition to the long Moore tubes permanently installed on the ceiling of special color matching rooms, as already shown in Fig. 12, there has been found a large field for smaller and portable white Moore light units. The standard method of installing one form of such an artificial daylight window is shown in Fig. 15. They operate on 220 volt, 60 cycle, alternating-current circuits and consume 2000 watts. About 0.5 of an ampere flows through the gaseous conductor. The 1.75 in. glass tubing is bent back and forth upon itself and in the rear are located the electrodes and feeding apparatus.

Fortunately the white Moore light combines with its ideal color values also an ideally low intrinsic brilliancy which does not outrage the eyes of the observer, and therefore when working by the light of these artificial windows the eyes of the color-matcher are not inconvenienced or his mind distracted from his work. It is the only artificial light that does not need a softening shade of some kind, *i. e.,* the light is generated at an extremely low intensity.

The very great importance of color in the practice of the profession of illuminating engineering is shown by the fact that there are invested many hundreds of millions of dollars in industries directly dependent on color values. Many of these classes of trade have already shown their appreciation of the very great advantage of being able to obtain a standard light for color values, but in each instance their color experts were incredulous at first, yet on actual acquaintance with the white

Moore light soon became enthusiastic over its exclusive and remarkable qualities, and stated that nothing further could be desired for a light to equal average daylight.

Unless we have carefully looked into the matter, the sur-

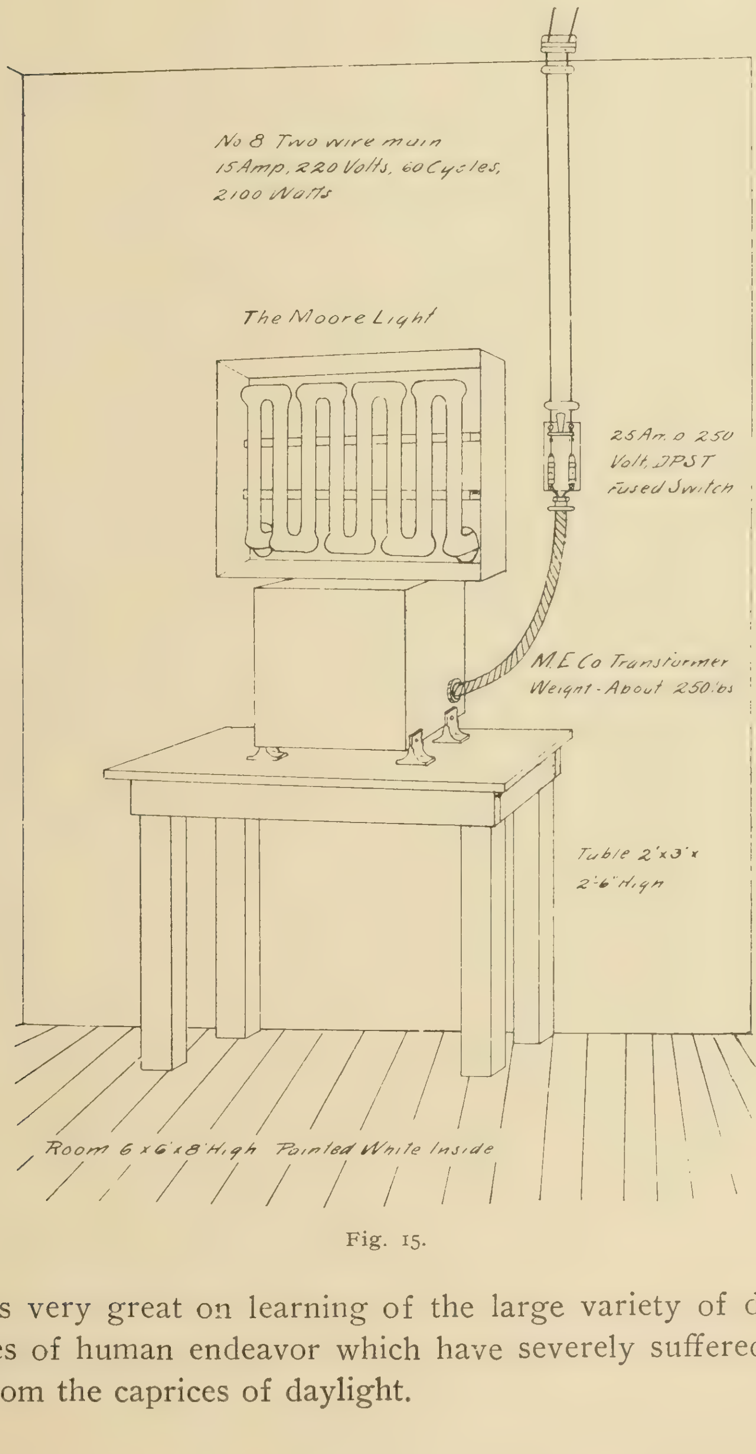


Fig. 15.

prise is very great on learning of the large variety of different avenues of human endeavor which have severely suffered in the past from the caprices of daylight.

The inevitable result in each case is the discontinuing of the use of daylight entirely, depending on the ideal artificial light. Its constancy is now highly prized, after thorough trials by many classes of business, not only for the increased profits resulting from its use, but also because it has brought about an emancipation from the continual aggravation due to daylight variableness.

The skein silk dyeing and finishing business has already been mentioned. Dye shops using the white Moore light run on regular schedule and where desirable operate at night. Re-dyeing and the holding over of work is done away with, thus effecting considerable economy. Experts dyers say their work is simplified and the uncertainty heretofore existing is now eliminated. The work at the looms can also be greatly improved by being able always to see the threads and the fabric in their proper colors.

The same applies to looms of the enormous woolen industry, as well as to its perches where the finished cloth is rigorously inspected and examined for flaws of all kinds. The dye houses of the woolen industry are also very extensive, as are also those used in connection with the manufacture of carpets of all kinds.

In the manufacture of cotton from the dye house and looms to the multicolored print goods, accuracy in colors is necessary, even to the large manufacture of gloves, hosiery, etc., also for kids and fancy leathers for many purposes, such as for automobiles, etc.

The application of the white Moore light to the dyeing of ostrich feathers is interesting.

Again the manufacture of wall paper as well as the accurate work of the lithographer and color press printer demands uniformity in the shades of color. In unlooked-for places the white Moore light has made itself very useful; for example, in metal ware companies which manufacture small articles like the exquisitely colored boxes used for talcum powders, soaps and numerous other toilet articles. It may require an educative campaign of some years' duration, but it has been predicted that finally in every kind of business but one kind of artificial light will be used,—viz., the kind that imitates daylight. As the fact

becomes more generally known that an absolutely satisfactory light for all color purposes is now available, it will have the effect of bringing to a much greater degree of refinement many manufactures, such as paints of all kinds, and the china, pottery and stained glass industries. Even in the textile industry the manufacture and marketing of certain classes of goods much desired has in the past, been considered impracticable, because there did not exist a standard light to make a uniform output possible. In the mineral world such a light is needed from the sampling and inspecting of the ores at the mines and the grading of pearl buttons up to determining the value of all kinds of precious stones. From remote ages it has been accepted as an unchangeable fact that the specific value of a diamond could be determined only by natural light, but now for the first time it is actually possible to sample all precious stones with far greater accuracy under the white Moore light than even under daylight. One stone may have far greater value than another stone of the same weight simply because it has a better color, yet under the ordinary incandescent lamp all diamonds have the same yellowish glint. Heretofore importers have found it necessary to sort their diamonds of about the same weights with extreme care and skill, only by a north light on a clear day under which conditions the color of the most expensive gems or "rivers" is a bluish white, while the more common stones or "capes" have a yellowish green color. These delicate but extremely important financial differences in shades of color are only discernible under daylight or the white Moore light, which is the first accurate reproduction of average daylight.

Again a light of standard color is needed in the manufacture of cigars or sugar, properly to grade them, but equally so it should always be utilized in attempting to judge the value of all art paintings. The old masters believed not in art, but in truth in painting, and the heighth of refinement in the production of works of art will be not as in the past, to wait for weather conditions propitious for work, but to execute the entire painting under the standard light for colors, and then since its spirit is dependent on its colors, judge it also under like conditions. There is no longer any good excuse for keeping art galleries closed at

night. One of the first applications of the white Moore light was to the photographer's art, it being recognized that a subject could be better posed if he looked perfectly natural, even if the natural light were not available. Besides this, the diffusive and actinic qualities of the white Moore light make it possible to produce results equal to those obtained by daylight, and of course far superior so far as uniformity is concerned.

Practically all that has been said thus far concerning some of the applications of the light of standard color has had to do with manufacturing, but in the borderland between manufacturing and retailing there are also many fields of usefulness, such as in medicine, the diagnosing of inflamed tissue at night, and the performing of serious surgical operations with safety.

It can now be said with some surety that there is not an occupation that cannot be pursued under modern artificial illumination as effectively as by daylight.

The sphere of activity for illuminating engineers as the matter of color values becomes more and more refined will become larger and larger.

On considering the retail trade, special applications for a cold white light suggest themselves,—for example the lighting of ice cream saloons and florists' shops, but in general it is logical to state that if the light of standard color values has been found an essential in the manufacture of goods of any kind, it should also be equally valuable in their sale. This is almost the equivalent of saying that ultimately the public will demand of all storekeepers that they present their goods for sale only under a proper light, that is, one that will not misrepresent them, intentionally or otherwise. In many stores the sale of silks, for example, can be perhaps doubled because the largest modistes now order their buyers not to purchase except during the middle hours of pleasant days, and the familiar scene of a clerk carrying a bolt of cloth long distances to a window will rapidly disappear. So also will all high grade tailors and clothing stores use the standard light and the public will shortly marvel at the enforced patience they have displayed every time they have made a purchase late in the afternoon or evening, in depending entirely on the word of the merchant as to whether the goods

were blue or black. One of the largest and highest grade ready-made men's clothing stores in this city today instructs its salesmen always to be sure that the coat, vest and trousers of a suit are tagged with the same number to be sure that they have the same color. This also applies to mid-day sales, because the high opaque backs of the show windows cut off almost all of the natural light.

Therefore, since large numbers of practical men in the arts have already adopted the white Moore light as their perfectly satisfactory standard it behooves this Society to act in accord with them and adopt it officially as the standard white light, and thereby render a great service to both practice and theory.

Too much importance can not be laid upon the unanimity of opinion of those who have used the white Moore light, especially when previous experience had trained them to be hypercritical and very exacting in their requirements, due to the many claims of various illuminants for perfect whiteness of light, which practical tests discredited.

The ample time that has elapsed has completely vindicated the writer's early claim and clearly indicates that there is every evidence that great good would be accomplished by the recommendation of this Society that this light be adopted as the standard for color values.

Therefore since the real ideal, daylight in the shadow, is at its best very variable, and since the most painstaking tabulations of its changeable moods, when averaged, result in values for each of the colors of the spectrum, substantially the same as those of the CO_2 spectrum, therefore the statement is warranted that nothing further need be desired.

But in addition to this it is eminently proper that a practical Society like the one I have the honor to address in this paper, give respectful attention and great weight to the overwhelming testimony of those who have personal knowledge of the great value of the Moore CO_2 light in the commercial arts. Ten thousand mill operatives have for the first time worked on a full schedule during the dark days of the past winter because of it. It is gratifying that the averaged tabulations of the scientists have accorded fairly well with the numerous findings of the ex-

perts of the industrial arts because for an exact knowledge of what average daylight color values actually are, there exist no greater authorities than they.

The commercial color matchers of the world have already quite definitely decided which shades of color are correct, and further that their values for average daylight were the same as those of the white Moore light. For many years the textile industry has been fully alive to the distressing changeableness of natural light. In several instances enormous establishments have been built up because they turned out an exceptionally uniform line of colored silks, for example, by doing all of their matching only during the middle hour of the day and only on days the weather of which closely approached the standard of weather they had determined upon. The hour of day, the climatic conditions and geographical locations, etc., necessarily caused some variations in each concern's idea of daylight, but now they can always refer to an ever present standard.

In fact, there has already asserted itself the natural tendency entirely to abandon daylight with its variableness and use exclusively the white Moore light, which course appears to be inevitable.

In the largest silk dyeing establishment, all goods are first dyed to match the sample handed to the head dyer, under the white Moore light, and then, usually by adding a further dye, are also made to match under an ordinary bat-wing gas jet. But the addition of another dye for the gas-jet matching must not interfere in the least with the original daylight matching. This is possibly due to the fact that a preponderance or deficiency of any color of a light will cause a like effect in the goods. In daylight and the white Moore light the quality of each color of the spectrum is properly proportioned or balanced.

For example, practical dyers almost always ask first when discussing any form of light, whether the yellows do not disappear, because this is one of the gross defects of most other forms of light when the attempt is made to use them for color matching. Some special forms of light like the intensified arc, for example, do fairly well in some portions of the spectrum.

but fail very badly in other portions. But the white Moore light covers the entire spectrum with perfect accuracy.

Since the highest authorities in the chemistry of dyeing admit that up to the present time there is no generally accepted theory, governing the art of dyeing, it is therefore all the more important and fortunate that there is available for adoption a thoroughly satisfactory universal standard of color comparison.

The object of this Society is to give equal importance in the study of illuminating engineering both as to its practice and its theory, and the practice of that portion of illuminating engineering confined to color has produced such an indisputable mass of evidence that this body is amply warranted in taking suitable action in the matter.

Most forms of artificial light have at times been vigorously presented as possessing color qualities that were the same as natural light, but much if not all of the acrimonious discussions resulting from such claims could have been and can be eliminated by first definitely agreeing on which of the many varieties of natural light is the most desirable to imitate. It is now almost impossible for some of our younger illuminating engineers to realize what it meant in 1894 when I stated that diffused daylight was the ideal light which we should try to imitate at night, to be informed by the highest authorities that "a white or daylight effect at night is unnatural and uncanny," and that "the natural color for a light at night time is red." As before indicated, the history of the color of all lights from remote ages of antiquity down to the present hour indicates a steady progression towards the blue white light of the vacuum tube, which, so far as color values are concerned, has reached the goal.

In this paper it is not claimed that the white Moore light imitates either direct sunlight or diffused daylight in *all* their qualities,—chemical, biological, optical, invisible radiations, etc.,—but it is claimed that the color values of all objects appearing under it are the same as those of the best form of average diffused daylight.

But what are average diffused daylight colors? They are not the colors an object has when exposed to the direct rays of the

sun. We are dealing with an interesting practical matter and are earnestly endeavoring to reduce our art of illuminating engineering to a science, therefore we must acknowledge the definite conclusion of the industrial and commercial world that the color values it and the best of mankind are vitally interested in, are those produced by a shaded sun.

Humanity spends a very small proportion of the total hours of its existence in the direct rays of the sun; and even if it desired thus to spend a larger proportion it could not do so because per year the total hours of direct sunshine in most portions of the habitable globe are very limited. No; both evolution and necessity make man a being who normally dwells under a roof, and therefore his practical standards must conform to his practical life. Of course, at times the quality of diffused daylight obtained in the open, directly under a clouded sky, is the same as that of light in the shadow of other objects. No greater authority on light has ever lived than Von Helmholtz, who, realizing the great difference in color values of the light direct from the sun and that in the shadow, gave his opinion that the best light to adopt as a standard would be that found immediately within a window.

A representative form of daylight is that reflected into a room from a mirror placed at an angle of 45° to the sky outside of an open window on the shady or north side of a preferably isolated building to prevent the direct sunlight from reaching the mirror and to avoid any disturbing reflections from surrounding objects.

The color values of some portions of the spectrum, for example, the blue, thus obtained throughout the middle hours of all of the days of a year will vary as much as 40%, but the average of the values obtained for each of the seven colors of the spectrum throughout the course of some years may each exactly conform to those of the white Moore light, which are always constant and instantly available. Of course there is no probability that any two days, months or years of natural light are exactly alike, and therefore it is an extremely fortunate scientific coincidence that the combination of an electric current with CO_2 produces color values which are the same as the

best form of diffused daylight. We therefore acknowledge per force the indisputable claim of daylight (not sunlight) as the real standard, but knowing its vital defect of grave variableness, substitute for it an equivalent that is as accurate in color as can be desired, but which also possesses the enormously valuable attribute of constancy. It is so simple that it can always be reproduced of invariable color qualities.

It needs simply to be fed automatically with pure CO_2 and its color values will remain constant throughout its entire life of perhaps over 5000 hours, after which new electrodes will probably needs be supplied.

This paper is confined to the applicability of the white Moore light as a standard for colors, but it is my conviction that the this light will later be also adopted as the standard of intensity, which is an added argument why it should now be adopted as the color standard. Various European professors have ventured the opinion that if the object of artificial illumination is the reproduction of daylight as a standard, finality is more likely to be approached by the use of tubes than bulbs It will be a fact of very great scientific importance to photometry of all kinds if the standard of intensity is at the same time the standard of color. It has been proposed to obtain this advantage in connection with a standard of intensity by combining certain portions of the radiations of perhaps three different sources, which, even though it were capable of being practically carried out, would be far inferior to a single source as regards simplicity.

It has also been suggested to obtain any specified spectrum approximating daylight by various screening processes, which is not comparable in simplicity with generating directly the spectrum desired. With either of the above methods the white Moore light plan would be highly desirable, if not absolutely necessary, as the method of unfailingly producing a spectrum of constant quantities as a standard to attempt to copy. After its adoption we would then be in a position to renew the attempt more accurately to determine the mechanical equivalent of "white" light. We would also soon become accustomed to the desirable habit of complying with every statement of the

efficiency of any light, its color. The automatic feed valve can be designed for very delicate adjustment, which will assure accurate reproduction at will, and thereby avoid the extreme sensitiveness of gases at low pressures, which have been described as one of the most trying and baffling departments of physical research. But the subject of the primary standard of light intensity is a very large one, and probably it will be wiser first to express the color values of all other forms of light in terms of an adopted standard. The preparation of the accurate preliminary specifications makes an ideal subject for students' theses under the guidance of professors well versed in such matters, or they could be written by the U. S. Bureau of Standards.

The probability of serious errors developing in reproducing absolutely the same color values is fortunately very small. Some of the factors involved are the diameter and thickness of the glass tube and its quality, the purity of the HCl, the purity of $CaCO_3$, the purity of CaCl, the purity of CO_2, the purity of the tube's electrodes, the amount of current passing through the tube, the degree of vacuum in the tube, etc. Yet most of these factors can vary to a considerable extent without changing appreciably the spectrum of the light.

Of course the spectrum should also be accurately determined and recorded in wave-lengths. It consists of so large a number of fine lines and so well distributed, that some spectroscopists have called it continuous, thus preventing it from being placed in the objectionable selective class of the mercury arc with its few bright lines. In fact spectrophotometer tests can be applied to the white Moore light just as they are to any continuous spectrum from a heated solid conductor.

In proposing a scientific standard, of whatever nature, it is well to consider whether it is adaptable to being international in its scope and thus avoid, for example, any repetition of the unfortunate international complications in the past of various units of light intensity. From this standpoint it is particularly desirable that a standard be adopted without further delay and so also is the white Moore light particularly suitable. If it were proposed that delegates from all parts of the world should decide on a standard spectrum obtained by averaging the natural

light of each country, great differences of opinion would immediately develop. For example, those from the Northern Hemisphere might specify a "north" light, and those from the Southern Hemisphere a "south" light. Again the latitude of a country like Germany, with its consequent average short day as compared with ours, might cause them to advocate utilizing readings in making up their average that were taken with the sun greater distances from its zenith, etc. From this the enormous superiority of the suggestion to adopt as standard for the whole world a light independent of natural conditions, is immediately apparent. It is also apparent that due to the very large number of variable quantities entering into natural light, that at best a so-called standard form of daylight could only be arrived at by arbitrary decision, which would also be forever subject to revision.

Some of the variables affecting the quality of natural light are: color of clear sky, white clouds, dark clouds, mist, rain snow, dust, smoke, other atmospheric impurities, proximity to water, near-by buildings, their color, character of ground, foliage, indoor observations, size of windows, north, east, south, west, outdoor observations, direct sunlight, geographical location, altitude, astronomical changes, time of observation, year, month, day, hour, minute.

Daylight is the real color standard because we now assume beyond argument that due to creation and evolution, the human eye is adapted to it. But it is thoroughly unreliable; therefore, it is logical and imperative that there be adopted a substitute for it, as a standard, which has its good qualities without its bad ones. Such a procedure is necessary in order to bring to a high state of scientific achievement, not only many sciences as well as art, but also many important industries. In fact it is very remarkable that the world has reached its present age and development without there having been adopted a uniform and international basis to determine exactly what is meant by the simple expression—"a white light," or even a "white color."

The "average daylight" determined upon by Professor E. L. Nichols in a paper presented to this Society in May, 1908, has considerably less blue in it than in the white Moore light. But

the Nichols spectrum, which is, comparatively speaking, very yellow, would not be accepted by the commercial world as being adaptable to its wants. It demands an "average daylight" under a roof. The 150 Nichols observations which were averaged, were taken directly under foreign skies. A direct sunlight spectrum contains much less blue, *i. e.*, much more yellow and red than the spectrum of diffused light from a shaded sun. The Nichols observations were taken in the open in varying weather and were therefore more liable to be affected by the sun. The "average daylight" spectrum obtained by Dr. H. E. Ives by tests made at the Bureau of Standards in Washington, D. C., has considerably more blue in it than the Nichols spectrum, yet not quite as much as that of the white Moore light. But the Ives average daylight was obtained from fifteen sets of observations obtained from fair and cloudy skies at a west window. If they had been taken at a north window, the final result might have exactly coincided with that of carbonic acid gas in a white light tube. In advancing the color matching claims of the white tube light several years ago, I was met with the premature criticism, based on simple observation, that it was too blue, more so than daylight—but various tests have since proved that daylight is often considerably more blue than it, again indicating that it represents an average. But in the last analysis there is no logical reason why the "average idea" applied to all knds of weather, should be adopted as the method of deciding on a standard, because we are endeavoring to find a practical standard for commercial use, and many color-dependent industries in the past have been compelled to cease activities until the weather cleared. Therefore it is more logical to decide on a standard that is equivalent of the best natural or daylight conditions, viz., the white Moore light, which is the only light for which such claims can rightfully be made. Since it is the first light to give entire satisfaction to those employed in color matching of all kinds, it is safe to say that a more satisfactory spectrum to adopt as the standard form of duplicating daylight will never be obtained.

At various previous meetings of this Society the author has suggested that some action be taken towards the adoption of

a light of standard colors, and now realizing that at the present time no such standard has been adopted and believing that it is a matter of great and immediate importance, and that there is a demand for such a standard by commerce and science, the author earnestly requests the president of the Illuminating Engineering Society to bring this matter to the early attention of the Council for consideration, and hopes that it may speedily result in an active committee being appointed to make thorough investigation and report its recommendation, with the ultimate idea of presenting the same before the International Conference on Electrical Units and Standards.

DISCUSSION OF CLIFFORD, IVES AND MOORE PAPERS.

Chairman E. L. Elliott. We have with us this evening the President of our Society, Dr. E. P. Hyde and I will ask him to take the chair for the evening.

President Hyde:—Now, gentlemen, these three papers are before the Section for discussion. The first by Mr. Clifford deals with some practical considerations of importance. For example, it must be patent to all of us at times how a room exquisitely decorated under daylight conditions depends almost entirely for its effect at night upon the scheme if illumination which is chosen.

The second paper by Dr. Ives contains perhaps the first summary of all the work which has been done up to the present time on this interesting subject. I might say that Dr. Ives' first measurements upon the Moore tube presented before this Society some time ago, were unfortunately not as accurate as those which he has presented tonight because of certain difficulties which were encountered and which were afterwards corrected.

In the third paper, Mr. Moore again brings to our attention the carbon dioxide tube as yielding light which approachs very closely in color to daylight and suggests that it may have a value as a standard of color.

These three papers are open for your discussion. I am sure that the questions presented in them are of interest to a great many members of the Society.

B. Jones, Jr.:—It is unfortunate that Mr. Clifford is not here to lend his personality to the reading of his paper, and to take part in a discussion that must otherwise seem somewhat futile and one sided. Mr. Clifford speaks with authority on this subject, and the mere fact that he has undertaken to present a paper is evidence, I believe, of a mutual relaxation of the untenable positions taken by both the illuminating engineer and the designer. One has only to listen to the general trend of the discussions at recent meetings of this Society to become aware of a decided change in the attitude of the members toward what may be called the aesthetic side of the design of illuminating equipments. We no longer hear the demands of the architects designated as preposterous. On the other hand there is ample

proof of an awakening among the members to the fact that the architect does frequently have correct ideas, and that when his ideas are properly carried out both by the engineer and the fixture designer there results something that is good and practical.

In this connection I must protest against such statements as appeared in a recent editorial published in a prominent electrical journal. This editorial advanced the proposition that artistic lighting and good lighting from the physiological standpoint were incompatible. Far from this being the case, it is true that *no system of illumination that is in any sense of the word dangerous physiologically can by any twisting of the term be called artistic.* The fact that any such system of illumination is productive of eye strain is, *ipso facto,* proof of its being inartistic. This means, of course, that much of the so-called artistic lighting that has been done is ugly, but does not by any means prove that good artistic lighting is impossible. It is just such contentions as those made in the editorial referred to that have done so much to retard the acceptance by the architect and the designer of illuminating engineering as a bona-fide profession, and have prejudiced against this Society men who know what good lighting is. It is unfortunate that such apparently authoritative statements should appear at a time so critical. For it is also true that the architectural profession as a whole is almost on the point of meeting us half way.

As has been said by several architects of standing, the worker in light has opened to the designer a vehicle for artistic expression that is essentially modern in character. I know of at least three modern monumental buildings in course of erection that have been literally designed around a system of artificial illumination, because the architect found among the numerous modern light sources means of producing most interesting and beautiful effects.

A. J. Marshall:—As a member of the Illuminating Engineering Society, and as one who has high appreciation of the beautiful and harmonious in our existence, I wish to express my sincere thanks to Mr. Clifford for the emphasis which he has laid upon the importance of giving larger recognition to the aesthetic features of lighting. The paper carries the greater weight because Mr. Clifford is an authority on the subject. Our Society in the past has concerned itself too largely with the

scientific aspects of the problem and has given too little attention to the more important factors, namely the physiological, and aesthetic.

Mr. E. L. Elliott:—Mr. Clifford has made some very valuable suggestions, the most startling one of which is that the illuminating engineer can be of assistance to the decorator. This suggestion is startling not because its truth has not been recognized in the past, but because it is the expression of a decorator's thought. That it comes from one who stands high in his profession is, I think, a most favorable indication that the illuminating engineer is coming into his own, for we of course recognize that his province includes in addition to matters of concrete values and measurements, artistic judgment and feeling, all of which together constitute the field of art.

I see no reason why—and I never have seen a reason why—an illuminating engineer because he is an engineer or because he takes that title should thereby have no appreciation of art or no right to express himself upon it. Surely illumination is connected with the arts of architecture and decoration as no other subject is, and if the decorator or architect is not to receive help from the engineer in this respect then there is something wrong with one or the other.

In regard to the subject of color, Dr. Ives has attempted to give a resumé of the efforts that have been made to arrive at average daylight—or, what amounts to the same thing, an average white light. I think we may sum up Dr. Ives' summary still more concisely by saying that one cannot get an average daylight; there is not any such thing, and you never have it any more than you will ever get the average intelligence of an audience, for the simple reason that there are too many variables, and, not only are they infinite in number, but the question as to how they should be weighted is absolutely indeterminate. Therefore, you can get no average. Dr. Nichols made a very elaborate series of observations and experiments and arrived at one conclusion. Dr. Ives, too, from a somewhat different viewpoint, arrived at quite a different conclusion. Now, there is a very great necessity in the use of illumination that there should be some standard white light, and it is important that that standard should give in its use an appearance to the eye which under

practical conditions will not differ from that of ordinary daylight. I will not say average conditions. The eye unaided, without the aid of any measuring instrument, will not detect color differences to probably a greater degree of accuracy than it can detect differences in illumination—that is, of intensity—and those will generally not come within 20 per cent. So that I conceive that it is not necessary that we have as a standard white light a source which, even if there were such a thing as average daylight, was absolutely the same. It is highly important in the art and in manufacture that we have a standard of whiteness of light, but I think it is even more important as a practical measure than that we have a standard of intensity, upon which so much work has been done.

Now, by all investigators it seems to be admitted that the light of the carbon-dioxide tube is very nearly average daylight —average daylight being determined by different methods. I believe, therefore, and I have believed for some time, and my belief is still further confirmed by Dr. Ives' summary, that the light of the carbon-dioxide tube meets all the practical requirements for a standard of white light. I think this is a great achievement in the progress of illuminating engineering: To have produced a light which is as good as daylight for determining color values and to have such a light reproducible with, I believe, a very considerable degree of accuracy for scientific purposes and a practically perfect degree of accuracy for practical purposes so that work in factories where a light nearly approximating daylight is required can be carried on every working day in the year and during the working hours of every day, is a remarkable achievement indeed.

I, therefore, put in the form of a motion the suggestion made by Mr. Moore at the close of his paper, that it is the sense of those in attendance at a meeting of the New York Section that the Council of the Illuminating Engineering Society should consider the adoption of a standard of white light.

(This motion was seconded by A. J. Marshall and was adopted by the members present.)

N. Macbeth:—In one part of Mr. Clifford's paper statements are made to the effect that in residences we do not require a white light, and we want a change from daylight, and that we

want a light having quite a considerable mellow quality. Then later on towards the end of the paper I understood him to say that we required a red blue light for rest and a red orange light for stimulation. Now, that would appear to me to be a contradiction. I think it is undoubtedly true that we require a red orange for evening. I do not know of any other explanation for the predominance of open flame gas burners still used in residence work.

The diagrams shown by Dr. Ives in his paper as well as other papers that he has given us at different times on this subject were very interesting. I think it must be somewhat of a surprise from the reputation that gas mantles have had for color, to find upon being scientifically investigated that they are pretty well placed so far as being close to white light is concerned. It might be interesting to know that while gas mantles have been commercially called "white" light and "yellow" light, manufacturers are now experimenting with a mantle that will be extremely yellow. I think it will be interesting to observe whether the decorators really want that kind of light.

The reports showing how near the gas mantle lights are to a white light I think bring out the point that Mr. Elliott raised that the eye is unable to judge colors at all closely.

In the matter brought up by Mr. Moore on the question of the white light in clothing stores, I would like to ask him in buying clothes by number is the intensity not quite as important a matter as the color, and that possibly a foot or 18 inches distance from this artificial window what would be the approximate brightness of an article with the reflection coefficient of dark goods being very low? I should think the intensity would play a very high part.

P. S. Millar:—As I recall Dr. Nichols' spectrophotometric tests, they were made in the region just north and south of the Mediterranean, and upon the ocean. Under such conditions the quality of light was probably quite different from that which is to be found in this country. I would like to ask Dr. Ives if this difference has been given due consideration in his study of Dr. Nichols' work.

From statements made in Mr. Moore's paper and from statements made by him elsewhere, I gather that long carbon dioxide

tubes have an efficiency corresponding to about 5 watts per candle, while short tubes such as that displayed here tonight, have an efficiency corresponding to about 15 watts per candle. I would like to ask Mr. Moore whether or not these inferences are substantially correct. In attempts to simulate daylight we have yet to see what may be done by using the intensified carbon arc lamp and modifying the quality of its light. Such an effort would appear to promise some measure of success.

I would compliment the gentlemen who arranged this meeting. Desiring to discuss color of light, they have obtained a paper by an expert physicist who considers the matter in its scientific aspects. They then arranged for a paper by a man who is an expert on the subject in its decorative aspects, and finally they have a paper by a man who has succeeded in making available an artificial light which is a more or less satisfactory equivalent of daylight. This shows recognition of the broad aspects of the question and is an excellent illustration of the principles on which our Society bases its efforts in seeking to advance the cause of good illumination.

W. D'A. Ryan:—I wish first to congratulate the Society on the excellent papers that have been read this evening.

Referring to the paper of Mr. Clifford, I desire to say that it is papers of this kind that will do the Society as much good as any papers that can be presented. The Society has without question done very remarkable work in its comparatively short life, notwithstanding that it has had many things to contend with. For example, we have in the field the so-called illuminating engineering salesman or specialist whose primary object in life appears to be in many cases, to make the tail wag the dog. We also have the mutual friend of the "intense brilliancy fiend" who convinces his poor victim that what he thinks he wants in the proper thing, and he gives him a light that will put his eyes out. Then, we have the man working in the opposite direction who favors totally concealed illumination, which leaves the victim's eyes in a condition where they cannot telegraph to the brain whether he is coming or going.

Now, there is no question but that extremely brilliant illuminants and well diffused illuminants have certain applications where they can be used to advantage, but unfortunately they

are pushed to such a degree for general lighting that many architects, engineers and decorators, particularly in the western part of the country, are beginning to think that the illuminating engineer is a joke.

On the subject of the aesthetic in the lighting field; I believe that in order to bring about as rapidly as possible a condition of improved lighting where we use the aesthetic in combination with the utilitarian, it might be well for the Society to form a committee to assist in the framing of laws for the prevention of criminal lighting.

It is not my intention, gentlemen, to "knock" in any way, but there are many of us who are interested in this Society and we would like to see it prosper. We would like to create a friendly feeling with the architects and engineers, and the majority of us are no doubt sincere and are working in this direction; but unfortunately there are persons, many of whom are not members of the Society, who are working to its disadvantage, thus making it more difficult for the Society to make the progress in certain important directions that it should.

On the subject of color: The Moore tube undoubtedly is an excellent light for color selection, although it is about as much off towards the blue as the arc light is off towards the yellow. It is not generally understood that the arc lamp is more yellow than blue. We learn from lighting experiments in various buildings, such as art galleries and factories where they match colors, that this is true to a considerable extent, but the arc light when pushed up to a proper degree of intensity and when properly diffused makes a very excellent substitute for daylight. I am not prepared to say that it is better than the Moore light, but my present impression is that the two are not very different. They both stand pretty well on a par for purposes of first-class color selection. Either one or the other is subject to some variation. I do not know to just what extent the Moore tube will vary under different conditions, but I imagine it is not very great; and the arc light can be controlled within very close limits.

Dr. Ives:—I shall not attempt to discuss a number of the points that have been raised owing to the lateness of the hour. There was one question asked by Mr. Millar in regard to the sky as measured by Dr. Nichols, calling attention to the fact that

these measurements were made in the region of the Mediterranean. Now, instead of explaining the discrepancy I think that works the other way, because his skies are so much more yellow than the blue skies of other observers, and the skies of the Mediterranean and the Alps are very much bluer than those that we are accustomed to find in our own neighborhood.

D. McFarlan Moore:—I do not care to make any remarks beyond answering the question in reference to the effect of intensity on color matching. Of course, with a large majority of illuminants the intensity does have a considerable effect on color matching. Practical experience has shown, however, that there is a remarkable freedom from any such trouble with the white Moore light. For example, that window can be adjusted for half its normal intensity and the color dyer will not raise any objection whatever, and they are probably the greatest experts on accurate color matching in the world.

President Hyde:—I want to personally endorse what Mr. Millar has said in regard to congratulating the New York Section on the very interesting and instructive papers which have been presented this evening. I hope this is a fair example of what you always have in New York.

Discussion at a meeting of the New England Section March 17, 1910.

THE LIGHTING OF A RUG AND CARPET STORE.

B. J. Bean:—The problem for consideration as noted by the plan is that of illuminating a carpet and rug store 102 ft. long and 26 ft. wide and 14 ft. 3 in. high, with shelving on both sides, reducing the width for the most part to 21 ft. We may assume that the shelves, containing dark rugs and carpets, should be sufficiently illuminated, that the colors and patterns may be easily discernible as well as the floor which is the horizontal plane of illumination, and also that the most efficient illumination adapted to the store is required. Uniformly distributed illumination is essential in a store of this character and the light sources should be free from glare. Many of us have asked from time to time that papers presented at these meetings be more elementary than have been, that we may receive more of the basic principles of this science and in view of this fact I have decided to have you consider with me two ways of illuminating this store,—first by single mantle units and second by inverted gas arc lamps. The flux of light method for calculating illumination problems lends itself readily for the practical gas man's use, and it would not be out of place to review in part what has been said and written regarding this method.

DEFINITIONS.

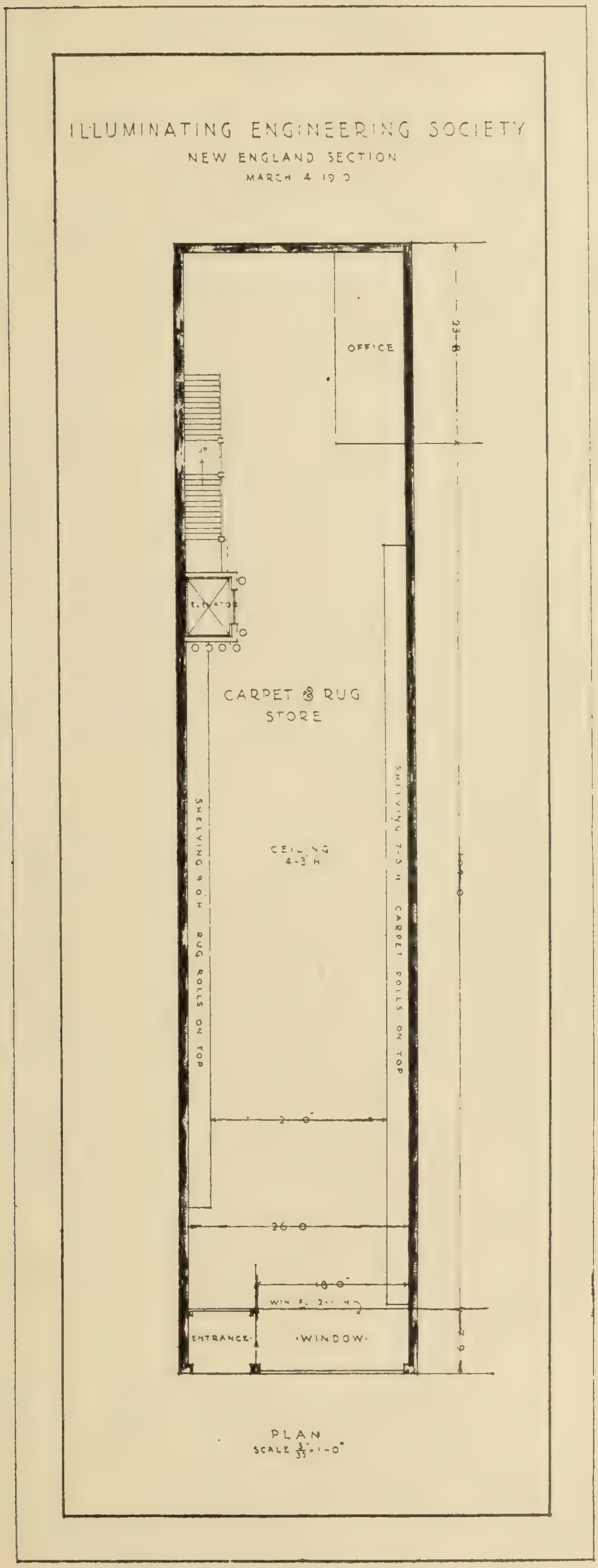
1. The unit of light intensity is the "candle-power."

2. The unit of light flux or quantity is the "lumen."

3. The unit of illumination is the "foot-candle."

4. A lumen is the quantity of light which will produce an illumination of one "foot-candle" over a surface one square foot.

To obtain the number of lumens produced by units within certain angles, Cravath and Lansingh give a method consisting of drawing a number of radial lines at angles which may be obtained by mathematical calculation. For our purpose, that of general distribution, the 60 degree angle may be taken.


ILLUMINATING ENGINEERING SOCIETY
NEW ENGLAND SECTION
OFFICE
23-8
CARPET & RUG
STORE
SHELVING 9-0 H RUG ROLLS ON TOP
CEILING
4-3 H
SHELVING 7-3 H CARPET ROLLS ON TOP
26-0
18-0
ENTRANCE
WINDOW
PLAN

Effective radials from vertical to 60 degrees:

12	degrees,	50	minutes,
22	"	20	"
28	"	57	"
34	"	25	"
39	"	11	"
43	"	32	"
47	"	33	"
51	"	19	"
54	"	54	"
58	"	20	"

Those interested in illumination problems would find it of advantage to draw off the lines with a protractor on a sheet of celluloid, to be kept for use. Placing this protractor of celluloid on the polar distribution curve, we may read the intersection of the radial lines and finding the average of our readings, multiply the same by 3.14 (the 60 degree lumen factor). The result will be the number of effective lumens. Finding two-thirds of this amount, that is, considering 33⅓ per cent. as a factor of safety, we may feel assured that our results obtained, by using this final amount as the number of lumens, are at least conservative. Several illuminating engineers have formulated rules and tables from data obtained through actual measurement of various installations, and we can do little better than be guided by their results.

Rule 1. Cubic feet per hour square foot equals foot-candle intensity multiplied by constant.

Knowing the constant for a given unit we may find the total number of cubic feet for the total area, and dividing by the nominal consumption of the unit we may find the number of lamps required. A rule answering this same purpose, which we will consider Rule 2, is as follows:

Rule 2. Find the cubic feet of gas per hour by multiplying the area in square feet by the illumination intensity required and divide by factor "lumens per cubic foot." Then to find the number of lamps divide by the nominal consumption of unit.

Using Rule 1,—the cubic foot per hour constant of the inverted burner equipped with clear prismatic reflector and clear cylinder, light ceilings and dark walls, equals 0.01. Assuming

4 foot-candles as adequate,—cu. ft. per sq. ft. equals 4 x 0.01 equals 0.04. The effective width for the most part of the main section is 21 feet and the length 102 ft. and we may consider the effective area to be

102 x 21 equals 2142.

2142 x 0.04 equals 85.68 cu. ft.

85.68 divided by nominal consumption of unit 3⅓ equals 25.7 (number of lamps required).

The ratio of length to width is about 5 to 1 and we should space the lamps as near this ratio as possible. Were this section a perfect rectangle we might add one lamp for even distribution making the ratio 3 to 9 with the total,—27 lamps. The rear section could be considered separately, or it would be as well to place our lamps, the spacing to be equivalent to that of the main section. Referring to plan 1 will show how the single mantle units might be spaced satisfactorily. Considering height, the lamps should be placed, as per assumption, so that the goods displayed on and above the shelves will be adequately illuminated. The higher lamps are placed the more evenly will the illumination be distributed on a horizontal plane, and placing these at a 12 foot height, will afford ample illumination on shelves as well as floor. It is well in most cases to lay out the plan in sections and by the point to point method check the intensity on the plane. With the installation as described, the intensity on the horizontal plane varies from 3.7 foot-candles to 4.8 foot-candles with an average of 4.03 foot-candles, a variation so slight that it is far from being objectionable. The intensity of the wall cases varies from 3.0 to 4.1 foot-candles.

The problem using five mantle inverted gas arc lamps equipped with alabaster globes and hung from central outlets is as follows: this time we will use Rule 2. (Area) 2142 x (Intensity) 4 divided by (Factor for 5 months inverted arc lamp alabaster globe) 65 equals 131.8 divided by 16.6 (Nominal consumption) equals 8 lamps. For uniform distribution add two more lamps for rear section, making total of 10 lamps and then space outlets equally distant one from the other (Plan 2). As before, it is better to hang the lamps as high as possible, 12′-0″ from plane. Checking the intensity by plotting the variation will be found to be from 5.3 to 2.3 foot-candles on horizontal plane

and on face of shelves from 3.3 to 2.3 foot-candles. Although there is in this case a greater variation of intensity using arcs than was found using single inverted units, this variation would not be objectionable and could not be detected by the eyes. It would be impossible to lay down any hard and fast rule regarding which type of unit would be better in every case, for it would depend upon conditions generally to determine the better for use. With all lighting problems, regardless of kind, rules and formulas must be supplemented by experience and common sense to insure satisfactory results.

T. H. Piser:—I would like to ask Mr. Bean if he does not think it would be better to use a slightly higher figure than 4 foot-candles on the plane. It would seem that with dark rugs there would be considerable absorption and we might require a little higher illumination.

B. J. Bean:—I think that depends upon the locality and general conditions of the place, but considering this from the standpoint of illumination I think myself that 6 candles would be better than 4 candles in a place that is so dark. You are utilizing your light here to illuminate both wall cases as well as to illuminate the floor.

T. H. Piser:—About what would the illumination on the side walls be if you had 6 foot-candles on the floor? Would it be in the same proportion?

B. J. Bean:—It would be about the same proportion.

R. C. Ware:—In most rug and carpet stores there is usually a dim religious gloom which makes it difficult to get what you are really after. I should think that 6 foot-candles would be preferable, and I do not believe you would get any undue light effect from the side walls, for the reason that in a room as narrow as this the light striking the lower parts of the walls would be incident at such an angle that the illumination would be less than the illumination on the floor where the light came in a more nearly perpendicular direction.

B. J. Bean:—I suppose in selecting the type of illuminants,—whether a large central source or a larger number of smaller units,—the wishes of the proprietor of the store must be taken somewhat into account, as he presumably is going to pay for it, and there are times and places where the appearance may be of

more importance to him than the actual high grade of the illumination. He may want his store to look bright from the outside as people look in. There are certain classes of stores which absolutely demand their light sources, and whose proprietors feel that unless they are getting their light sources they are not getting what they want, and I presume it is the duty of the illuminating engineer to strike a balance between the demands of his profession and the wants of his customer. So in this case I think that perhaps might have a great deal to do with deciding which should be used, whether a lamp like the arc lamp or practically three times as many smaller sources. As has been said, local circumstances must finally be considered.

R. C. Ware:—Individual light sources will, of course, give a very even and satisfactory illumination, but I think that in general practice it will be found that where so many units are necessary and such a large area has to be covered, the bother of turning on and off these individual lights, unless arranged with some general switch, would be too much for the average storekeeper. From that point of view the arcs would be preferred by the customer and also for the reason that they are more spectacular in effect and give the appearance of more light in the store, though there may be actually less illumination.

T. H. Piser:—I would like to ask Mr. Bean about his consumption, where he uses arcs and single units. Apparently he has about the same intensity on the plane. Perhaps we could get a comparison between the use of those two units on the total consumption.

B. J. Bean:—Using prismatic reflectors with single units, the consumption is 100 cubic feet against 167 cubic feet with the arc lamps.

N. W. Gifford:—Where close economy is practiced, as it is sometimes in lighting, with the single units the merchant, if he was displaying light colored goods altogether on his floor, as for instance some lines of matting, might turn out one row of lights, —say the central row, and still get plenty of light. I have in mind one customer who has a store with gas arcs of a type whereby a part or all of the mantles can be lighted, and I believe it is his general practice as the shades of evening fall, to turn off one or two mantles in each arc and then as the darkness

grows, to turn on more of them. He thinks he is saving some money and I presume he is but it merely goes to show the variety of ideas you must be ready to meet.

L. Brent Foster:—One of the gentlemen spoke about the customer objecting to expense. My practical experience has been that the customer will say: "I am burning so many lights here,—how many are you going to burn?" In other words it is his bill that counts. With an original installation we do not have so much trouble, but if you can show him where he can reduce his bill he is pretty well satisfied and will let you go ahead.

As I understood the question here, we were to merely light the store, which is 102 feet long. In lighting a carpet store, as one gentleman has said, we do need a strong light, but you want to take into consideration that 4 foot-candles is very good light. In desk illumination, which perhaps requires as much light as any normal condition, 5 foot-candles is ample. If you get 4 foot-candles practically even with proper reflectors, I think you will have no trouble with the intensity. I figured at about 4.2 foot-candles. The factors to be considered are how much light we want; how we shall get it; what we wish to light; the plane of illumination and quality of light. The quality of the light in this case is almost as important as the intensity, for this reason,—a carpet store has got to be illuminated by a quality of light which will in some way bring out fairly the effect of daylight, and in trial of our reflectors I found that the satin finish reflector to be as near sunlight as is obtainable and I have therefore used it in this case. I have illuminated this room 83 feet back. The portion to be lighted is then 21 x 84 or 1764 square feet. How are we going to distribute the light and where are we to place the lamps? It just happens in this case that it comes out very nicely. 100 watt tungsten lamps will just fit in there, but in some cases that is not so, and we would have to get the proper illumination with some other size of lamp. First I found my area in square feet and then determined the foot-candles I wanted. Then I determined what factor I wanted as a divisor. The divisor is different for different light sources. In our particular case I am using 4.2 because I am using satin finish reflectors. The walls are dark and the ceiling light. The color of the walls and ceiling deter-

mine your factor. The first thing is to divide the room lengthwise in half. This does away with a big part of the problem. We are proceeding upon the plan of general illumination tonight. I have divided the space into squares of 10½ feet each, and have 83 feet back to go. There are seven of the squares along the sides. The shelves do not run back the entire distance so in that case I put some light in the rear where it is needed. With 100 watt lamps I found by using 17, one in the center of each square, that the illumination comes out almost even. Each of these squares of 10½ feet is illuminated by one 100 watt lamp with I—9 satin finish reflector. How high shall these be? We come now to the shelves. The shelving in this case is 7 ft. 5 in. in height. These shelves are filled on the top with carpeting. This particular shelf is 9 ft. high packed with carpeting, but underneath is also filled with carpeting, giving us a dark wall. As I said at the beginning, the plane of illumination is the floor. Now we have to take in the practical end of it. They do not sell the carpeting from nine feet above the floor. They sell it from the floor. The customer may say he wants to see some pattern up on the shelves but they do not show it from the shelves. They show it on the floor. There will be light enough on the shelves to see all that is necessary. We will place the reflectors 9 ft. above the floor or plane of illumination because we must have a strong light on the floor. With an intensive type of reflector we see that we get a pretty intense and uniform light on the floor. It does not take very much imagination to take a space 10½ feet square, place a 100 watt lamp above it in the center and see that there is no part of that space where you will not get an even and strong distribution. As the lights are uniform throughout the room, the result will be uniform. You could turn out some of the lamps and I may say that it is a very simple thing to put in a switch which will command four lights at a time. This illumination is obtained by the formula $\frac{\text{area} \times \text{foot-candles}}{\text{factor}} = \text{illumination}$,—this case being divided by the proper factor,—and on this occasion we consider walls and ceiling dark, we divided by 5 with clear reflectors and if they are satin reflectors we let it down a little more. That is only the first part of the problem. In this particular room it worked out nicely. But on the other hand if

this room had been ten feet wider, you see it would have thrown off this whole scheme, and in that case you would have to refigure this light for distribution. I should probably have used 150 watt lamps then. I believe the principal factor in illumination is light, if you get it where you want it and get the quality, which I believe you will with a tungsten lamp and satin reflector. If we put the lamp 9 ft above the floor, and use the intensive reflector, we have even distribution of light. Then comes the last question which brings up the objection to general lighting, that is, shadows. I believe it was Dr. Bell who said that a room without shadows is just as bad as a room with too many shadows, and I have found that true in my experience. The eye must have something to grasp. A little shadow nere and there is not bad, and the only real objection that I have heard constantly put forth to general lighting is this question of shadows. I think we have proved that we can light a room by general illumination and have it lighted well. I could have paid attention to this part of the store here, of course. I understood, however, that the lighting of the carpet room was what was wanted. I think lighting a window is a matter that rests largely with the proprietor, as to how much he is willing to pay for it. I have seen windows in Jersey City with 275 foot-candles. I think window lighting is an unsatisfactory subject for discussion as to intensity for it rests so largely with the proprietor, as to the amount of light he is willing to use.

C. W. Cartwright:—Mr. Foster spoke of a condition which would exist if the store was ten feet wider. That would be about half as wide again for the main portion of the store. Why would it not be advisable under those circumstances to use lighting units of the same size, only to use an additional row?

L. Brent Foster:—I think to get the ideal illumination you are right. When I tried that scheme out first I had three rows in there, which was more the ideal illumination, but as as been said, when you put in too many outlets the customer complains. If I had the say of it I should put three rows in, but I am afraid if I should do that the customer would object.

R. C. Ware:—What would be the effect of extensive reflectors instead of intensive?

L. Brent Foster:—An extensive reflector reflects its light almost directly from the globe. One shelf is 9 feet high and the other

one 7 feet. An extensive reflector 9 feet from the floor, where the plane of illumination is a desk, is all right. With an extensive reflector the light directly under that reflector is very much less than the light at 45 degrees. The plane of illumination in this case is the floor, and the light has to be strong. With an extensive reflector you would get what you needed in your light in the middle of the floor, but in other places you would be in shadow very strongly on the floor. Give the extensive reflector a spread of light of 10½ feet and it is at its best, but you have only five feet here and you will catch the extensive reflector at its weakest point. If its plane of illumination were 2½ or 3 feet, it would be all right.

A. T. Sampson:—What would be the effect if you used the focusing type of reflector on a spread of that kind? We have had some very good results with it.

L. Brent Foster:—If you used in this particular case three rows of these lights you would get very excellent results.

A. T. Sampson:—Would you not get good results with two rows? There is considerable spread to them.

L. Brent Foster:—Yes, but at the expense of the shelf lighting.

C. H. Smith:—I would like to take exceptions to one of Mr. Foster's remarks. I think the day has passed when the customer considers his lighting bill entirely. When the tungsten lamp first came out it was sold by men who dwelt upon the merits of its low current consumption. I do not believe that condition exists now. The man of to-day is not trying to cut down his current bill, but is taking three times the illumination he had before and is pleased with the proposition he has. I think that is the condition that exists to-day, and I think the lighting companies have found this true, and that is the reason they push the tungsten lamp as they do. If they thought the tungsten lamp would really reduce the current to one-third of their output they would not push that lamp. Of course the tungsten lamp has made them sell heaters, etc., but the merchant cannot do as he is doing in his store by reducing his current bill.

A. T. Sampson:—I find that if a dealer fits out his store so that it is lighted 20 or 50 per cent. better than his neighbors, they will very soon get into line.

H. W. Karstens:—At the present time I am on industrial plant lighting only, but previous to that I did a lot of work for a

lighting corporation in New Jersey, and during that time complaints came in one after another of bills being too high, and in many cases I found, as Mr. Smith says, that the merchant was looking for results and did not think he was getting them. He was kicking about his bill, but it was because he was not getting results even though his bills were high. In one case I found a merchant whose bills were $75 to $80 a month. He put in tungsten lamps and cut down the bill to $45 or $50 a month. He had a basement and back room which he had not been lighting before, and he was so pleased that he said he could now afford to light his basement and back room. The first thing we knew there was an additional amount of $20 per month. He then put in an electric sign, saying he was now getting results, and to-day that man is paying $110 a month and is satisfied with the results he is getting. That proves that in all cases they are not looking for an economical way of lighting only.

In industrial lighting we are talking absolutely against the use of flat shades to-day. We are putting out almost entirely bowl type reflectors, and a man looking up at the bright light sources, as one gentleman brought out, becomes used to it and in many cases we have got to use bare lamps. When the men come to look up at their unit it is very deceiving. They are not looking at the plane they are working on but at the light source. I find considerable trouble in factories and mills. The operators are accustomed to using a flat tin shade with bare lamps exposed. The eye has become ruined and when I come along with a bowl type reflector and cover up the filament they say it is not satisfactory. They have got to educate themselves to the use of the reflector.

In the store under discussion the quality of light would be just as essential as the quantity. In a large furnishing house of which I know, they had of course different grades of rugs, and for the cheaper grades they used carbon lamps. If they used tungstens they would show up the material too much and could not sell the rugs, so they had to use carbon lamps on the cheap grades to make them appear warmer in tone. In this store under consideration I think with satin finish reflectors and tungsten bowl frosted you would get very good results. But according to this diagram I would not use anything other than the intensive type If you used a strong concentrator you would get a spot light.

TRANSACTIONS OF THE
Illuminating Engineering Society

VOL. V. MAY, 1910. NO. 5

MINUTES OF COUNCIL MEETINGS.

MAY 12, 1910.

At the Council meeting held May 12, those present were: President E. P. Hyde, Louis Bell, L. B. Marks, Joseph D. Israel, C. O. Bond, George Ross Green, A. S. McAllister and Preston S. Millar.

An abstract of the minutes of the previous meeting was read and approved. President Hyde then stated that he had explained to prominent members of the Chicago Section that on account of the arrangement with the Johns Hopkins University the tentatively extended invitation to hold the annual convention in Chicago could not be accepted at the same time. The Chicago Section, Dr. Hyde said, was well pleased with the selection of Johns Hopkins University for the convention and with the lecture course arrangements.

L. B. Marks, chairman of the finance committee, read a report of which the following is an abstract. The committee met May 12th and approved the payment of vouchers 495 to 497 inclusive and vouchers 498 to 518 inclusive, aggregating $837.38. The committee recommended that the Society accept the proposal of W. S. Pangborn to prepare a monthly trial balance and audit the books of the Society once a year at a cost of $75.00 annually. Upon motion duly seconded and carried Mr. Pangborn's offer was accepted.

The question of a more prompt issuance of the Society's Transactions was formerly discussed. The sentiment of the meeting was that an effort should be made to have the Transactions appear regularly and as promptly as possible after each monthly meeting.

Preston S. Miller, General Secretary, presented a financial report of the Society for the first four months of 1910. During this period, according to the report, the receipts were $5610.21 and the disbursements $2350.85, leaving a surplus (May 1st) of $3259.36; accounts receivable $2106; accounts payable $498.02.

The report included a status of the membership, which showed that 63 were lost through resignation and decease and that 278 members were delinquent.

A Committee on Section Development, the appointment of which had been under consideration for some months, was appointed by the President and approved by the Council. The committee consists of the following:

General Secretary, Chairman, *Ex Officio;* Secretary Chicago Section, *Ex Officio;* Secretary New England Section, *Ex Officio;* Secretary New York Section, *Ex Officio;* Secretary Philadelphia, Section, *Ex Officio.*

Upon motion duly seconded and carried, Dr. McAllister was appointed a committee of one to look after the indexing of the Society's Transactions, the index to be ready August 1st and to cost not more than $100.

As to the policy of exchanging publications, while the maintenance of a library of exchange publications was not deemed advisable, the desirability of distributing the Transactions broadly was acknowledged by the meeting. Such practice it was thought would, at least, benefit the Society indirectly. After a discussion the General Secretary was requested to present at the next council meeting a list of desirable exchanges which might be added to the list.

A letter was read from Professor Richtmeyer of Cornell University asking that a chapter of the Society be established at Cornell. The advisability of this procedure was discussed at length. It was admitted that the Society's objects would be promoted by having sections at technical schools, but that the time was not yet opportune to institute such branches. The secretary was directed to write Professor Richtmeyer that the Council would consider his letter and later on such plan as he proposed might be followed.

The following applications for membership were presented, all of the applicants being elected:

BEEDLE, H. W., Bell Telephone Co. of Can., Montreal, Can.
BROOKS, JAMES C., Phila. Elec. Co., 1000 Chestnut Street, Philadelphia.
CHAPMAN, H. W. Holophane Co., 30 Church Street, New York.
CLOVER, G. R., Cooper-Hewitt Elec. Co., 40 Dearborn Street, Chicago.
DODSON, HERBERT K., 100 West Lexington Street, Baltimore, Md.
HARMAN, GEO. H., Mitchell Vance Co., 836 Broadway, New York.
PRESBREY, JOHN S., Holophane Co., 36 West 39th Street, New York.

ROBB, JAMES S., Mitchell Vance Co., 507 West 24th Street, New York.
SCRIBNER, I. F., Amesbury, Mass.
TOPPING, ALANSON N., Instr. Elec. Eng., Purdue U., Lafayette, Ind.
VAUGHN, FRANCIS A., Vaughn & Meyer, 271 31st Street, Milwaukee.
WENZEL, HERMAN W., 2209 North 22d Street, Philadelphia.

The names of the following deceased members were dropped from the roll:—C. J. Toerring; H. J. Buddy.

SECTION MEETINGS.

PHILADELPHIA SECTION.

A meeting of the Philadelphia Section of the Illuminating Engineering Society was held April 15, 1910, at 8:15 p m., in the assembly room of the Philadelphia Electric Company building, 1000 Chestnut Street. There were 78 members and 21 visitors present.

Wm. Copeland Furber presented a paper entitled, "Architecture and Illumination." The paper was illustrated by lantern slides, showing effects of illumination upon architecture in many parts of the world, chiefly in Germany and the rest of the continent.

NEW ENGLAND SECTION

The meeting of the New England Section on May 9, was called to order by Mr. J. S. Codman in the absence of the chairman. The matter of revision of by-laws, on which notice was given at the last meeting, was taken up for discussion, and it was voted that the by-laws be amended as previously indicated, for the purpose of bringing them into harmony with those of the parent society. Mr. Codman then called upon Mr. Baker, who read an interesting paper dealing with street illumination. A discussion followed, after which the speaker was tendered a vote of thanks. There were nineteen present.

CHICAGO SECTION

By courtesy of the custodian and chief electrical engineer, the Chicago Section of the Illuminating Engineering Society met in the Federal Building, on Thursday, May 19, to inspect the lighting arrangement of the building.

Mr. Richardson, chief electrician, conducted approximately twenty members of the Section through the four Federal court rooms, which were lighted with several rows of 40-watt tungsten

lamps studded in the ceilings, together with numerous side wall bracket lights.

As the side walls of these rooms have marble panels up to within approximately 15 ft. from the floor, the lighting effect was not all that could be desired, but Mr. Richardson explained that they were working to improve that condition. The lighting in the court room was not adequate to properly illuminate the costly paintings located around the borders of the rooms, and Mr. Richardson explained that he had tried several methods to accomplish the desired result, but owing to the layout of the rooms good results were practically impossible. He further explained that trough lighting a few feet in front of paintings at the top would serve admirably for the purpose but the construction of the building made this impossible.

The corridors were well lighted exclusively by small ceiling fixtures, employing 40-watt tungsten lamps. The lobby proper was lighted by studded lamps in the various columns with a large dome in the top.

Mr. Richardson conducted the party through the main sorting room on the fourth floor, which was equipped with Cooper-Hewitt tubes for the general illumination, and series tungsten lamps for the lighting over the sorting cases.

Mr. Richardson carefully explained the various appliances and arrangements used for operating the machinery and handling the material, after which a short meeting of the Section was held in Mr. Richardson's office, Mr. Albert Scheible presiding.

Secretary T. R. Beebe outlined the report of the General Council made April 12, calling special attention to the resolution to extend a vote of thanks to the Chicago Section for its invitation to hold the next convention of the Society in Chicago, but which it was not considered advisable to accept, owing to the plan for a series of lectures at the Johns Hopkins University.

Chairman Scheible announced the appointment of the following nominating committee to report at the June Meeting for the annual election of officers:

Messrs. Keech, Howe, and Barnhardt.

A vote of thanks was tended to Mr. Richardson and to the custodian of the Federal Building.

A paper presented at a meeting of the New England Section of the Illuminating Engineering Society, Boston, Mass., April 11, 1910.

STREET PHOTOMETRY.

BY LOUIS BELL.

This is really a very informal talk on the problem of street photometry—the particular things which one encounters when he goes outside of his comfortable photometer room and undertakes to form a judgment (be it more or less correct) on the light which is being obtained in the street, for the purely utilitarian purpose of evaluating that light for practical use. As we all know, photometry is not an entirely easy matter at best. Even the best of our instruments and the most reliable of our standards still give us outstanding errors of a degree which is large compared with most other physical measurements. One can measure 1/1000 of a millimeter in evaluating the length of a meter. In the matter of weighing one can weigh a kilogramme without any particular difficulty down to one part of a million. In measurements of resistance one can perhaps not get easily quite as high a figure of accuracy as that but can do very creditable work indeed. But when we come down to photometric measurements it means not to one part in a million or to one part in a thousand, but to one part in a hundred, or one part in three or four hundred in very careful work.

So we must realize that we are dealing in all photometric work not with the highest degree of precision but with a degree of precision which is, commercially speaking, reasonably satisfactory provided it is carried out with all the necessary refinements. Our standards of electromotive force may perhaps be down to one part of a thousand easily or with difficulty (according to the care we take) but when it comes to photometric measurements we are tackling a thing of entirely different character. We are up against the power of the eye to discriminate between two shades which are nearly alike and yet not quite alike. It is stated by Helmholz that this fraction varies from about one part in 50 to about one part in 150 under various circumstances. With very careful conditioning of the eye we can

do rather better than that, so that on the whole in the laboratory (granted the comparison of two lamps of not too widely different intensity and not too different color) one can come down to a precision which is well under one per cent., depending again somewhat on the training of the eye, the experience of the observer and the character of the apparatus. I usually expect to make the actual settings within one-half of 1 per cent. by the use of a Lummer-Brodhun screen and a carefully darkened photometer room. With great care the same apparatus can work down to perhaps one-fourth of 1 per cent. of average error. With the Bunsen photometer, as commonly used, the variation would be two or three times as great as this. With certain forms of the Bunsen photometer (in which the grease spot is not a grease spot but a translucent material between two opaque substances) forming a carefully shaped narrow pointed and many pointed star, the variation may be cut down to a mean deviation of one-half per cent.

That is all right in the photometer room, but on the street your troubles begin. In the first place you are dealing usually with lights of different color from the standard, and that introduces at once the errors of heterochromic photometry. Then instead of having a standard lamp worked off a large storage battery under the most favorable conditions, you have a small standard worked off a battery with all the errors of the voltmeter added to it, a lamp which is subject not to the variations of the laboratory but to the variations which you find in the difficult work on the street, with varying stray light and varying conditions and surroundings, so that the instrumental errors are probably at least twice as great, and more likely three or four times as great, as they are in the case of a laboratory photometer.

Nevertheless, if you could get within one or two per cent. for your illumination on the street, there would be very little reason to complain, but it is the unfortunate fact, as all of us who have gone into street photometry have found to our sorrow, that the instrumental errors are only the beginning of our troubles. In the first place think what you have to do when you are going out on the street to measure the light given by a street lamp. We have all our common photometric difficulties to begin with and then we have the still greater difficulties which are incident to

the fact that we are dealing with a light, of the constancy of which we are not sure, or rather of the inconstancy of which we are sure.

Take, for example, a street Welsbach light. Now the Welsbach light has a pretty good reputation for constancy. Indeed, as lights go, it is not bad; but we have no method of measuring the pressure which is being applied at the moment to that lamp. We know that the pressure varies. We know that the drafts around the lamp shift its illuminating value to a very considerable degree—10, 20, or 30 per cent.—and a very curious fact has come up with respect to the inverted Welsbach light which otherwise is very beautiful, that it is hypersensitive to changes in pressure, for the very simple reason that the Bunsen flame in these lamps is driven down hard against the natural currents of air. Every shift in the wind, every little puff of air, every change in pressure of gas, becomes exaggerated. So instead of having the nicely adjusted lamp which we have in the laboratory, we have a light (and a very good light it may be) the value of which is shifting, not in a periodic manner but in an erratic manner.

However continuously we use our photometer, we are in close touch with these irregular variations, and we cannot tell where we are because we cannot get a meter into the pipes or gas mains for measuring the pressure and telling us the facts. Now suppose you photometer a lamp of that kind ever so carefully, your errors of photometry may be in all about 2 per cent. if you are lucky and careful. You come around, we will say, at 8.15 and you get a value, which may be 10 candle-power high; you come around again at 9.30 and you get a value, which may be 15 or 20 candle-power low; and so on all through the evening.

The consequence is that when you start out on a career of street photometry you may by accident get the mean value. The chances are extremely great that instead of getting that, you either get some group of the high values or a group of the low ones; and if you come back in an hour or so you do not know whether you are going to get a pressure which might average up, or one which will produce an added error in the same direction. The result is that the light as measured on the street,

even with all the photometric errors eliminated, is subject to an error of 10 or 20 per cent. I do not think that is exaggerating it at all.

Suppose you say that you know the Welsbach is variable, so you will take an incandescent on the street. We will start again, with our mean value. Your incandescent lamp is, for a given current, fairly uniform, but the given current we will say is 5 amperes. The light should be uniformly steady. But no man is in position to say whether he is getting one-tenth ampere high or one-tenth low at any particular time, on account of shifting in the regulator, on account of inevitable leakage or a dozen other things which may temporarily for a few moments or half an hour shift the value up or down. Consequently you will get perhaps a very steady value, perhaps not. You may get a light high here and you may get a light low there. If you measure at one point and by happy chance get the right value, when you come back again you may get another mean value perhaps one slightly high or slightly low. The variations in this case are comparatively small, but added to your necessary errors of photometry they are preceptible. They cannot be neglected.

When we take the arc lamp see where we are. The arc lamp let us say starts in at its mean normal value. In the first place you have a shifting of the luminous value as the arc goes through the process of burning up to its regulation point and then feeding, and the result is that you get a considerable variation covering a period which depends on the adjustment of each lamp. You might find the feeding period of the lamp and from that form a fair judgment as to what the mean value would be, but the arc is walking around the electrodes and you have then a perfectly unknown curve which is superadded to the other. The consequence is that the whole phenomenon becomes *aperiodic*. The feeding variations are very nearly periodic according as the lamp is set. The variations added by the walking around of the arc on the electrode may amount to 10 or 20 per cent. even, and you cannot know just what the conditions are. Then there are still added to that variations of a purely accidental character which no man can tell anything about. The light is continually fluctuating, always giving variations, but variations of unknown sign and unknown amount.

Consequently when you come to photometer the lamp, even supposing your photometric work is carefully and reasonably accurate, as it generally is, you are rather in a quandary as to what one of the diverse values shall be read and what one of the diverse values represents something like the mean candle-power of the lamp. Now the variations from moment to moment and from ten minutes to ten minutes could be evaluated by a sufficient number of readings if it were not for the influence of the psyschological element. You set up your photometer and start to balance it against an arc lamp. Every man who reads a photometer has his own habit of balancing. He may catch the lamp at one point at its normal. He may habitually wait until it steadies down at a low value, quite unconscious of the habit, or he may on the other hand instinctively catch the high spots only and get a value 5, 10, 15 or 20 per cent. higher than the normal. I have met photometrists who quite unconsciously had the vicious habit of reading consistently either high or low, and once formed the habit is hard to break. The result is that you have for your errors, A the photometer error, plus B, the error due to the actual fluctuations of the lamp, plus C, the personal equation of the man who is making the readings. The sum may be plus or minus to an extent depending on the maximum fluctuations of the light. The arc with its rapid fluctuations usually accentuates the personal error but nevertheless you are subject anyway to the other two.

The net result is that the error in street photometry (I mean the unavoidable errors so far as we are able to ascertain them) is likely to be a good many times the bare photometric instrumental error and that, too, is aside from the question of color.

The question of color, so far as photometry of street illuminants goes, I think is rather exaggerated. The actual errors in comparing two lights of varying colors are obviously somewhat greater than when comparing lights of the same color, perhaps two or three times as great, but with a little practice in reading street lights it is astonishing how correct a judgment of general illumination one will form,—or at least how uniform a judgment one will form, which is not the same thing but still shows an encouraging tendency toward uniformity.

When it comes to comparing very dim lights,—that is street lights, at practically the maximum distance, you may find a good deal of trouble in photometry. I think one can make with the street lamps of the colors now customary, errors perhaps as great as ten per cent., owing to the color difference, but such errors are made only at a distance from the lamps at which the illumination is of no conceivable practical use. That is the only saving clause in the color photometry of street illuminants. When you get out to a point where the light is a few thousandths of a foot-candle you make a large error, perhaps due to this trouble, but inasmuch as the illumination at that point is not of any practical service the error may be neglected, for the simple reason that you have no business to use your photometer at any such point.

In other words there is very little use in evaluating light which is practically, for seeing purposes, no light at all; so that substantially you have the three errors only to deal with, the fluctuation error, the actual photometric error and the personal equation.

Now the point to which all this is leading up and which I desire to point out in this very brief discussion, is that in the face of those comparatively large errors which are due not to the instrumental error itself but to the inevitable fluctuations of light, whether gas or electric, and to the personal errors of the observer. Owing to a combination of these errors what you get on the street is necessarily not a nice and quantitative measurement of the illumination but a rough working measurement within limits. The bearing of that on practical street lighting I think is this: that any attempt at nice evaluation of light on the street is practically futile. You can make a pretty good estimate. You can make an estimate plenty good enough to tell you whether the lights are doing their duty or not, but you cannot say within a large margin of error just exactly what the light is doing.

As a practical matter for those buying and those selling light, I think the conclusion to be drawn from this situation is as follows: that all the attempts which have been made from time to time to sell street illumination by measure are subject to errors too large to permit of their being considered of any great practical value. Time and again it has been suggested that the

proper way to sell light was to sell light; that if you undertook to deliver we will say 40/100 of a foot-candle at a particular place, that light should be measured and if it showed only 37/100 of a foot-candle you should pay in accordance. If you get 43/100 you should pay in accordance with that. Now practically even with the best illuminants we have including all the variations of light, the photometric error and the variations due to dirt on the globes, whatever their character, you can get only somewhere near to the light actually delivered on the street, even with a small number of lamps, let alone all the lamps in the city. Hence I am strongly disposed to the opinion, based on a rather long experience, that any attempt to sell light on the basis of the illumination delivered at a particular point as determined from the investigation of all the lights in the city or a number of them is a thing which is bound to lead to all kinds of difficulties and litigation.

Where a city is paying two, three or four hundred thousand dollars per year for light, variations of 10 per cent. mean a large sum, a sum too large to lightly be considered; and inasmuch as the variations in the integration of light on the streets will amount in most cases to at least that, it seems to me necessary to conclude that any attempt under practical working conditions, even with the very steadiest and best illuminants, when you take into consideration the necessary errors and the necessary variations caused by difference of cleanliness of the globes and the inevitable conditions in service, to measure the illumination as a measure of price is simply bound to lead to great trouble.

I say so particularly because it has been suggested in some rather influential bodies that illumination was the thing to be sold and therefore you ought to measure it. I think a very brief consideration of the necessary difficulties with the fluctuation of the light with the condition and character of the surrounding globes, plus the photometer errors, will show that any such nice measurements as should determine the payment of half a million dollars a year more or less are quite out of the question.

What can you do, then, in the practical problem of selling illumination on the street, whether of gas or electricity? Well, you can do this. You can sell service with a given standard type of lamp which can be investigated *in extenso* in the lab-

oratory and the range of variation of which can be fairly well evaluated by sufficient pains. Granted a service of a certain number of hours a year with this light consuming a given amount of gas or current at a given pressure, you can agree that a certain price shall be charged and paid for this service for so many hours per year with a specified illuminant, the consumption of energy or material in which shall be specified and the character of which is open to investigation, and you can then specify that this equipment shall be kept in first-class working order. You can go a little further even than that and can find use for your photometer. You can say that a light which is normally, although perhaps not specified in the contract, of 100 candle-power shall not have certain large variations or shall not fall below a certain amount and you can set that variation at a point which will cover the aggregate errors in your photometer.

In other words you can use a street photometer very successfully to show whether the light which is actually being given out at a particular distance and in a particular way is materially above or below a certain amount that shall be agreed upon before-hand. You may have 5, 6 or 10 per cent. possible error in your photometric measurement but you can set your nominal photometric value X far enough below the point you would like to reach if you could measure with absolute precision to be sure within all ordinary reason that when you specify that your 100 candle-power lamps shall not be less than 90, we will say, you will not get any readings less than 90 unless the lamp is badly out of order.

So in spite of the difficulties of application, in spite of the necessary errors which are due not to the instrument itself but to to the conditions of the illuminants and the personal error of the observer, you can so determine the use of your photometer that you can show with fairness to all parties that the light is doing what it should. You may say that if I have a 100-candle-power lamp and set my photometric limits so that, I will be sure to get 90, I am really beating myself out of at least 10 candle-power. That is not true, however, because if the lamp sags to 90 you are liable to get an adverse reading on your photometer and then your operating company has to brace up and see that it does not get down to that point, else it will be liable to be caught

by the inevitable errors in the measurement which are by no means negligible.

Hence we may conclude, after all is said and done about photometric measurements on the street, that for a quantitative estimate of the exact illumination or exact quantity of light the instrument can only give a rough approximation. On the other hand, if you are working with known illuminants the variations of which you can reasonably predict, as you can with any illuminant if you have tested it in the laboratory, you can use your photometer to insure that it shall not fall below a certain specified minimum. In other words you can make sure that while you may be getting a larger candle-power from the illuminant you are at least getting what you calculated on and therefore the photometer errors can be wiped off the slate, because you are always at liberty to set the photometric limit so as to include any reasonable errors which may be made.

It is possible, therefore, to get a photometric test of illumination, even under the most adverse conditions. You cannot get what you would get in the laboratory, that is an absolutely quantitative evaluation of the illumination; but you can insure getting a certain minimum, and if you set the minimum wisely you may be sure that you are getting all that you can reasonably expect with that given illuminant. In closing I wish to be again distinctly understood as not to be inclined to knock in any way the precision of photometric measurements; but what could you do in your laboratory if you had the lamps on a commercial circuit with an irresponsible boy juggling the rheostat whenever he saw fit, or what could you do if you had the gas lamp on a pipe too small with an indefinite number of persons making all kinds of drafts on the mains without your knowledge? The fluctuations which occur are things which, while they can be somewhat guarded against in practice, cannot be guarded against fully. You can, however, make sure that you are getting at least a certain amount of light and if you set that amount of light so that you will get good illumination in the street, you can eliminate the practical difficulties of street photometry as a commercial proposition.

But when it comes to the measurement of street illumination values for purely scientific purposes, your troubles begin and

they will, so far as I am able to judge, exist until we get conditions of service in illuminants and freedom from the variations in electric or gas pressure and weather conditions which we cannot now determine, and I think it is safe to say that in the New England climate the weather conditions are something that no man can ever approximate.

DISCUSSION.

Theodore Piser:—Is it possible by increasing the number of readings, to get something nearer the normal?

Louis Bell:—If you increase the number of readings enough, you can get nearer the normal by far than if you take a few readings, but inasmuch as you are working the lamps all night and working in any given system from a half score to a half thousand lamps, you cannot sample the lamps accurately by testing one, two or three. You cannot be sure, with anything except a tremendously burdensome number of readings extending into the hundreds, that you are really getting the precision that your average would indicate.

Prof. Puffer:—Dr. Bell's remarks call up a good many attempts to measure lamps which beginning somewhere about 1885 and continuing ever since, covering about all the types of lamps most of you have seen and many which some of you have never seen, and embracing about all conditions of service, from the best to the kind I hope you never saw or want to see. I can recall a great many things that Dr. Bell has not touched upon which would, perhaps, be interesting to you. When it comes to measuring lamps on the street the first thing you think of is what you will take along with you and how in the world can it be taken. I have taken all kinds of standard photometers and various types that I have tinkered up myself. The light standard which must always be carried with one has varied from a standard candle, which is a pretty good standard if you protect it from the wind, to the Bunsen lamp and the incandescent lamp. It is unnecessary to say that the incandescent lamp is far better than any other although the battery with the ammeter is too heavy. As far as the form of the portable photometer is concerned, it has varied all the way from a cigar box with one end knocked out and a partition put in to a regularly built instrument. The results obtained with the cigar box were surprisingly good. The sort of photometer which perhaps might be called a luminometer has been used to a considerable extent and while it would never be used in the laboratory under conditions where accuracy was desired, I personally want to say that in my hands a calibrated luminometer has been found accurate to an extent which is better than 10 per cent. and not perhaps as good as 5 per cent.

That, however, is with skilled observation and standardization before going out on a trip and again when coming back, and the method of reading is not by reading something you know all about, and could recognize by a flash of lightning once in a while, What you want to take is a list of stock quotations or printers' "pi" and read backwards. If you have light good enough for that you can tell what you are reading, and it will be impossible to read unless there is the light. With proper instruments and proper observers it is unnecessary generally speaking, to spend very much time on instruments. Be sure they are reasonably correct and that you know how to use them, because the mistakes of the test will not be in the instrument; they will be in the operator's failure to use it properly out on the street and at the right time. The greatest instrumental error I have found in street photometry is one most of you would think plays no part, and it is the measurement of distances from the light sources down to the screen of your photometer. You go out at short notice and have no idea how high the lamps are or anything about it. You take a man with a tape measure and you try to measure the angle and calculate the distance. Any percentage of error is doubled in your results. Personally, I think this is the greatest error that ordinarily enters into the work. The reason we make this photometric test of the lamps is because some of us, either the committee paying for the lights or the experts of the company furnishing it, fear dishonest practice. I think you will agree with me that in many cases there are claims for candle-power or illumination made which are absolutely false or else the conscience of the person making them in very elastic. I have some newspaper clippings which came to me within a year, in which a company desired to be released from a contract under which it was obliged to use the old-fashioned open arc with clear globes, and they decided to use the modern arc lights which took about one-half as much energy, and somebody invented a very accurate and careful comparison. The old-fashioned arc was put upon a short post and beside it was the new arc. The old one was put on the old fashioned 9.6 ampere circuit and the other in the modern circuit. The committee went out to measure these lights with a luminometer. They called upon a policeman and everybody else they could find

to peek into the box. The old-fashioned arc, as you all know, gets its maximum brilliancy at about 40 degrees downward, and the new arc as near the horizontal as you can get. The poor old-fashioned arc light was not much on the horizontal and the new one was, and the reading was done on the horizontal. The result came out almost a tie. The two lamps were nearly equivalent. I think if they had been treated according to Dr. Bell's idea the result might have been very different. Under the question of tests I think Dr. Bell will recognize such ideas as this,—the light expressed in terms "of the average maximum is about" so much. That simply means that you will wait and take the biggest readings you ever saw. If you record the readings under these conditions they will be entirely wrong as one light may have many maximums and not much else, but another light may give a good steady light with less light than the others. If you do not count it in when your carbons do not come part, etc., then your readings are false. I discovered the following state of affairs in some readings taken by several groups of observers. One group of men with two photometers were reading beautifully, but they were both very anxious to get the same readings. They were more interested getting check readings between themselves than anything else. Another observer was proceeding after the fashion of a man in an auto. He was simply sitting on the tops of the curves as he went along. He got about 20 to 25 per cent. higher than anybody else. The only way to take these readings is to have two men and have the scale of the instrument the observer looks at a purely numerical one. One moves the photometer adjustment back and forth and must forget where he left the thing the last time, which is best done using a handle which requires many turns to produce a certain variation and the other man reads scales. In that way if you read rapidly as possible and for a considerable time you get a fair value of the lamp. When it comes to a statement of what the permissible limits shall be, I think that an expert called to help anybody in specifying the limits for street lighting should take into consideration the fact that the company probably means to be honest, and that the people who are buying the light probably intend to be honest; but that there are on both sides men who are mistaken in the application of honesty and

men who are always looking for a rebate, and these are the men you have to look out for in writing specifications, so that there will be nothing left for them to pin a rebate on unless it properly belongs to them. I always use such clauses as shall define say an arc lamp, by the candle-power and also consider the average watts in the lamp, the trim and the globes especially because I have seen them make a difference of 50 per cent. in the readings. You must to specify the carbons and have a set delivered to you. Then you must specify what the average candle-power shall be under best possible conditions and the minimum under which it shall never go in service. Than you have something to talk about, provided you do not do the foolish thing of putting the minimum so high that the lamps cannot deliver even that minimum. Then you can advise the committee if the lamps are properly run and the company is bound to make good, and if one now and then comes down to the low point, you may then point out that it is only *one* lamp and that on the whole the lamps on the system are all right and doing their work. With the incandescent lamp testing is a very simple matter compared with the arcs, for all you have to do is to tap the current, insert your ammeter and read the current, and photometer the lamp there or in laboratory. I want to call your attention to two or three points I noted. Dr. Bell referred to the trouble in connection with the photometry of Welsbach lights. I have met a good many of these difficulties and I might say that in one case an automatic pressure recorder on the service during an extended series of tests lasting six weeks, varied in the same evening from 1½ to 3½ inches, and it is unnecessary to say that the candle-power of the light was not very satisfactory. Dr. Bell neglected to state in the beginning of his talk the first requirement for measurement. The first requirement is to have a quantity which remains still long enough for one to measure it. If it will not be still long enough to measure, you cannot get any reading at all.

C. W. Cartwright:—What has been found the most satisfactory standard lamp to use in a photometer in making measurements of street gas lamps?

Louis Bell:—I always use an incandescent lamp. The color difference is not enough to bother. That is to say, the color

difference between an incandescent lamp and the straight Welsbach is of course very noticeable, but the error which is introduced by it is much smaller than accidental variations in the lamps themselves due to puffs of wind, changes of pressure, etc.; so that while you might possibly imagine that you would get errors with an incandescent standard, particularly a tungsten standard, the results in the precision of reading are quite satisfactory. The trouble is not nearly as much as you might imagine. I suppose some men might attempt to use a flicker photometer out on the street, but I have never had the courage to do it. It is difficult enough in the laboratory.

Theodore Piser:—In the newer types of arc lamps, like the metallic arcs, are the errors as large as in the old-fashioned arc lamp?

Louis Bell:—The errors are different. I think the aggregate magnitude is not far from the same, but they are of a different character. The feeding period is longer. The mechanical fluctuations are I think quite as great, and the periodical fluctuations from the shifting of the arc are about the same. The difference is not very material in the matter of steadiness. Any of them are subject to fluctuations which will throw you out, and the color difficulties are not very serious. The flame lamps give a very good color for comparison and the magnetites do not give half as much difficulty as they would seem to at first thought.

C. W. Cartwright:—What other kind of measuring standard can you use if an incandescent electric lamp is not available?

Louis Bell:—A Hefner lamp or a Bunsen lamp was used as a secondary standard and was fairly satisfactory, but the incandescent is easily the most convenient and best and the color is excellent.

C. H. Williams:—No matter what instrument you use for your measurements, you have to depend on the sensitiveness of the eye and its ability to recognize small differences in the intensity of light, especially with the small amounts of light that you are using in the measurement of street illumination. The personal equation is a very considerable one. The retina of one eye will be more sensitive to these small differences of light and will have a different Fechner's fraction than the retina of another eye; and I remember very well one evening when Dr. Bell.

one person and myself were making some readings of signal lights at a distance of half a mile using the same lights under the same conditions. We came out with a series of curves all of which were different but which were all parallel. That is to say one of us read a little higher and the other a little lower than the one coming in between but the relative differences that we made between the different lights were the same. To get the best results it may be necessary to standardize your observers and see what the individual equation of their eyes is as shown in their readings.

A paper presented at a meeting of the New York Section of the Illuminating Engineering Society, New York, April 14, 1910.

ON FINITE SURFACE LIGHT SOURCES.[1]

BY BASSETT JONES, JR.

A paper on this subject, presented by me before the Illuminating Engineering Society in the spring of 1909, appeared in the TRANSACTIONS of April, 1909. In view of the fact that several errors appeared in the final print, and that some of the formulas have been criticised—in one case I must admit justifiably—I purpose here to discuss certain of the results obtained, and, where necessary, to re-write others.

The general analytical method employed is, of course, not new. In fact the general case was given some time ago by P. G. Tait in an article on "Light," *Encyclopedia Brittanica*, ninth edition. Incidentally, definitions of "illumination," "brilliancy," and "intensity" are given in Tait's article which are, to-day, exceedingly pertinent, as well as a suggested use of the potential function in discussing surface sources, of which more below.

Three assumptions are made in the paper above mentioned, as well as in what follows:

1. That the inverse-square law holds for infinitesimal surface sources.

2. That the amount of radiation in any direction from an infinitesimal surface source is proportional to the cosine of the angle of obliquity.

3. That the thickness (volume) of the source need not be considered in discussing the distribution of the light flux in space.

It was found by tests of a number of available sources that the first and second assumptions were approximately true for source areas as great as 4 sq. ft.

These experimental sources consisted of rolled opalescent, sand-blasted, and etched glass plates having various forms of surface treatment, illuminated by means of incandescent lamps contained in a reflector possessing some novel features of design, and so arranged as to project a constant normal light intensity upon one side of the source, through which it was transmitted and diffused.

[1] This paper should be read as an appendix to the paper in TRANSACTIONS for April, 1909.

The only effect of changing the thickness of the source was to smooth out the polar surface and to make the assumption as to the inverse-square law and the cosine law for larger areas more accurate. Whether or not it is necessary to consider the volume of self-luminous sources in investigating the theoretical flux distribution outside of the source, I cannot say. Certainly all the radiation emanating from such a source must pass through the bounding surface; and if the flux is so distributed at the surface as to comply with the first two assumptions, it seems only necessary to consider the flux as originating at the surface. What actually goes on inside the source has no effect on the illumination produced, except as it affects the surface flux, and this last once determined will furnish us with a working basis. Furthermore, the introduction of the idea of source volume into our calculations produces complications which add greatly to the difficulties of arriving at practical results without any seeming compensation therefor. The treatment of the problem relating to volume of light sources can probably be reduced to a discussion of surface conditions by the application of some theorem analogous to Green's Equivalent Stratum in problems relating to volume electrification or magnetification.

It is all very well to obtain highly complex formulas and to insist upon their correctness because they take account of theoretical details. But when we know that no matter how carefully our calculations are made, they are certain to differ widely from experimental results, it seems almost too academic to spend time and energy on refinement. What the practicians need are formulas that do not require the use of mathematical terms, the very meaning of which he has forgotten, if indeed he ever knew them.

In order to show how unnecessary mathematical refinement is in our problem, I have introduced below a detailed check calculation of the intensity due to a finite plane circular source using the method of harmonic analysis, which in this case as in many others becomes so ponderous as to be of little or no utilitarian value. Of course what constitutes the proper degree of refinement is largely a matter of judgment—a fact that is true of almost all application of theory to engineering practice.

While on the subject of "applied mathematics" perhaps I may be permitted a further digression. Dr. E. P. Hyde has likened physical mathematics to the sculptor's chisel; but we need not go very far into the philosophy of the matter to see that the simile is not a good one. In mathematics one never finds anything in the solution that is not already implied in the hypothesis, theorem, or determining conditions with which one starts. Nothing is added by the development, and nothing is created. The sculptor, on the other hand, *creates*. He produces something that is entirely original with himself and of which there is no previous indication save his own imaginative power. Logic is surpassed. One does not reason out a work of art; nor is the statue imbedded in the marble block, requiring but the chipping away of the rough exterior casing.

However, to establish a starting point, we may write down the formula for the apparent normal intensity of light flux at any point on the axis of symmetry of a plane circular source. It is

$$I = \pi i \sin^2\beta \qquad (1)$$

where i is the apparent normal intensity per unit area of the source, and β is the angle subtended by a radius of the source at the point in question. It is to be noted that in (1), πi is the flux emitted by the source per unit area on the assumption that the cosine law holds for such areas—an assumption that experiment seems to confirm. The difference between the value of I obtained by (1) and the intensity obtained by considering the source as a point source having an intensity equal to Ai, where A is the area of the surface source is expressed in per cent. by $\sin^2\beta$.

When, now, we desire to find an expression for the normal intensity at *any* point under the source, we meet with a problem of some difficulty that can only be solved by a method of approximation.

If, in Fig. 1 we let $ds = dxdy = \dfrac{rdydr}{(r^2 - y^2)^{1/2}}$ represent an infinitesimal source element, and if we assume that the cosine and inverse square laws can be taken as truthfully describing the variation in space of the apparent intensity due to the flux

through this element, we get, as an expression for the correspond-

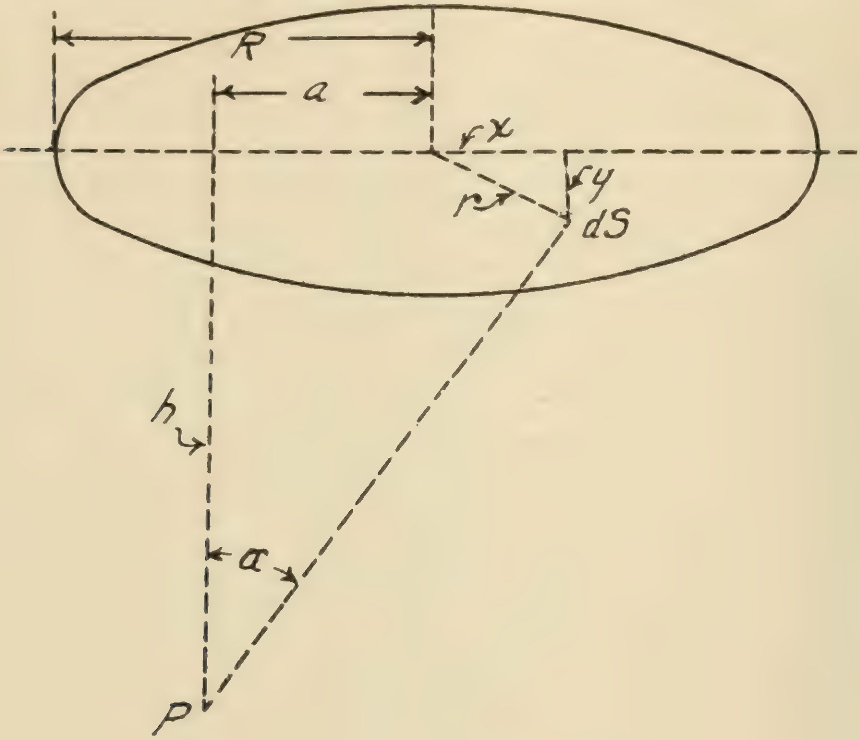


Fig. 1.

ing component, i_n, of the normal intensity at P, distant a radially from the center of the source and h below it,

$$i_n = \frac{rih^2}{(r^2 - y^2)^{\frac{1}{2}}(h^2 + a^2 + r^2 + 2ay)}\, dydr.$$

The expression for the total apparent normal intensity, I_h, at P, then "takes refuge in the definite integral"

$$I_h = ih^2 \int_0^R \int_{-r}^{r} \frac{rdydr}{(r^2 - y^2)^{\frac{1}{2}}(h^2 + a^2 + r^2 + 2ay)}. \qquad (2)$$

This expression can be evaluated approximately by a device, or, I dare say, it can be evaluated for any given case, by a tedious computation of elliptic integrals.

The approximate evaluation of (2) may be taken as

$$I_h = \frac{\pi ih}{2a}\left[\tan^{-1}\frac{(R - a)}{h} + 2\tan^{-1}\frac{a}{h} - \tan^{-1}\frac{(R + a)}{h}\right], \quad (3)$$

a result that is practically true when $h \gg R$.

In the paper above mentioned the integral and its evaluation were written down wrong. The first error was obvious; the second was not. Nor do I think the corrected evaluation (3), will be much more obvious, the difference consisting merely in the addition of the factor $\frac{\pi}{2}$. While the expression (3) is not rigorously correct, it is sufficiently exact to enable us to calculate values of I_h over a range of values of h and a large enough to include nearly every practical problem in illumination dealing with plane circular sources. If we had evaluated (2) by any regular method, granting this is possible, the result would have been too complicated for use. The proof of the pudding is. after all, in the eating thereof, and this we shall try later.

The expression for I_h has the form $\frac{f(a)}{F(a)}$ and takes the indeterminate form $\frac{0}{0}$ when $a = 0$. To find the true value of (3) subject to this condition, we must find the value of

$$\left[\frac{\frac{\partial}{\partial a} f(a)}{\frac{\partial}{\partial a} F(a)}\right]_{a=0} .$$

It is

$$\frac{\pi}{2} ih\left[\frac{2h}{h^2 + a^2} - \left(\frac{h}{h^2 + (R-a)^2} + \frac{h}{h^2 + (R+a)^2}\right)\right.$$
$$\left. + \tan^{-1}\frac{R-a}{h} + 2\tan^{-1}\frac{a}{h} - \tan^{-1}\frac{R+a}{h}\right]_{a=0},$$

or

$$\frac{\pi}{2} ih\left[\frac{2}{h} + \frac{2h}{h^2 + R^2}\right] = \pi i\left[1 - \frac{h^2}{h^2 + R^2}\right],$$

which is

$$\pi i \sin^2 \beta.$$

The expression (3) therefore reduces to (1) when $a=0$, a necessary result, if (3) is correct.

It will be observed that when h is large compared with R and a, the term outside the bracket in (3) is large, while the sum of the terms within the bracket is very small and subject to great

inaccuracies in computation. The expression can, however, be given a form suitable for computation under these conditions.

Let us expand each term within the bracket according to the known form

$$\tan^{-1} x = x - \frac{x^3}{3} + \frac{x^5}{5} - \frac{x^7}{7} + \cdots, \text{ when } \tan^{-1} x < \frac{\pi}{4},$$

or

$$\left.\begin{aligned} \tan^{-1}\frac{R-a}{h} &= \frac{R-a}{h} - \frac{(R-a)^3}{3h^3} + \frac{(R-a)^5}{5h^5} - \cdots, \\ 2\tan^{-1}\frac{a}{h} &= 2\left[\frac{a}{h} - \frac{a^3}{3h^3} + \frac{a^5}{5h^5} - \cdots\right], \\ \text{and} \quad & \\ \tan^{-1}\frac{R+a}{h} &= \frac{R+a}{h} - \frac{(R+a)^3}{3h^3} + \frac{(R+a)^5}{5h^5} - \cdots. \end{aligned}\right\} \quad (4)$$

The values (4) can be used in (3) only when the largest values of $\tan^{-1} x$ is less than unity; that is, when $(R+a)<h$. If $a = R$, then (4) can be used in (3) only when $2R<h$. Substituting (4) in (3), and rearranging we get

$$I = \frac{\pi i h}{2a}\left[\frac{6R^2a + 2a^3}{3h^3} - \frac{10R^4a + 20R^2a^3 + 2a^5}{5h^5} + \cdots \right.$$
$$\left. - \frac{2}{3}\frac{a^3}{h^3} + \frac{2}{5}\frac{a^5}{h^5} - \cdots\right] \quad (5)$$
$$= \frac{\pi i R^2}{h^2}\left[1 - \frac{R^2 + 2a^2}{h^2} + \frac{R^4 + 5R^2a^2 + 3a^4}{h^4}\right.$$
$$\left. - \frac{R^6 + 9R^4a^2 + 14R^2a^4 + 4a^6}{h^6} + \cdots\right]. \quad (6)$$

In the neighborhood of $a = \left[\frac{h^2 - R^2}{2}\right]^{1/2}$, (6) becomes rapidly inaccurate, but can be used for computation, with the error confined to approximately 0.01 up to $a = \left[\frac{h^2 - R^2}{8}\right]^{1/2}$, which is sufficient for most practical purposes when (3) cannot be used. When $a = 0$, (6) reduces to

$$I = \frac{\pi i R^2}{h^2}\left[1 - \frac{R^2}{h^2} + \frac{R^4}{h^4} - \frac{R^6}{h^6} + \cdots\right]$$
$$= \frac{\pi i R^2}{h^2}\left[\frac{1}{1 + \frac{R^2}{h^2}}\right] = \pi i \sin^2 \beta,$$

when $h > R$

The expression inside the brackets in (6) is rapidly convergent for small values of $\frac{R}{h}$, and (6) can therefore be used where (3) is impracticable. For values of h approaching $(R+a)$ computation by means of form (6) becomes unwieldy and limited, but within this region form (3) can be computed with considerable accuracy.

Since we have shown that (3) and (6) are correct when $a=0$ we must now show how much they deviate from true values of I_h for values of a greater than zero; that is, for points not on the axis of symmetry, subject to the condition that h is always greater than zero.

To find an expression for I_h that can be compared with (3) and (6), we shall follow Tait in assuming, as a mathematical convenience, a potential function that describes in mathematical terms the character of the light field due to what may perhaps be called the "strength" of a light source.

If V is the value of this potential function at any point (x, y, z) referred to the same co-ordinates as the surface source itself, then at this point,

$$\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2} = 0, \qquad (7)$$

an equation corresponding to Laplace's equation in problems where the slope of V is an actual forcive.[1] Since the field has circular symmetry about the h axis, equation (7) may be written as follows, in terms of spherical co-ordinates having the center of the source as origin,

$$r \frac{\partial^2}{\partial r^2} (Vr) + \frac{1}{\sin\theta} \frac{\partial}{\partial\theta}\left(\sin\theta \frac{\partial}{\partial\theta} V\right) = 0 \qquad (8)$$

where r is the radius vector from the center of the source, and θ is the angle between r and the normal to the source at its center.

The intensity normal to the plane of the source at any point of the field is given by

$$I_h = -\frac{\partial V}{\partial h}. \qquad (9)$$

[1] v. Hyde, "Geometrical Theory of Radiating Surfaces," *Bureau of Standards Bulletin*, 3, No. 1, p. 101.

It is to be noted that the value of I in any direction can only be obtained from the expression for V when the direction of I and the values of the co-ordinates of the point at which I is desired are so related that there is no flux taken in the opposite sense. In other words, if I is measured normally to an imaginary transparent screen placed in the path of the light flux, I can only be obtained from V by differentiation with respect to the direction normal to this screen when the reverse side of the screen is not exposed to the light flux.[1] Thus a screen placed anywhere in a plane normal to the plane of the source that cuts the source will be illuminated on both sides, and the value of I normal to this screen is not the value obtained by differentiating V with respect to this normal. If the plane of the screen passes through the axis of the source then the actual

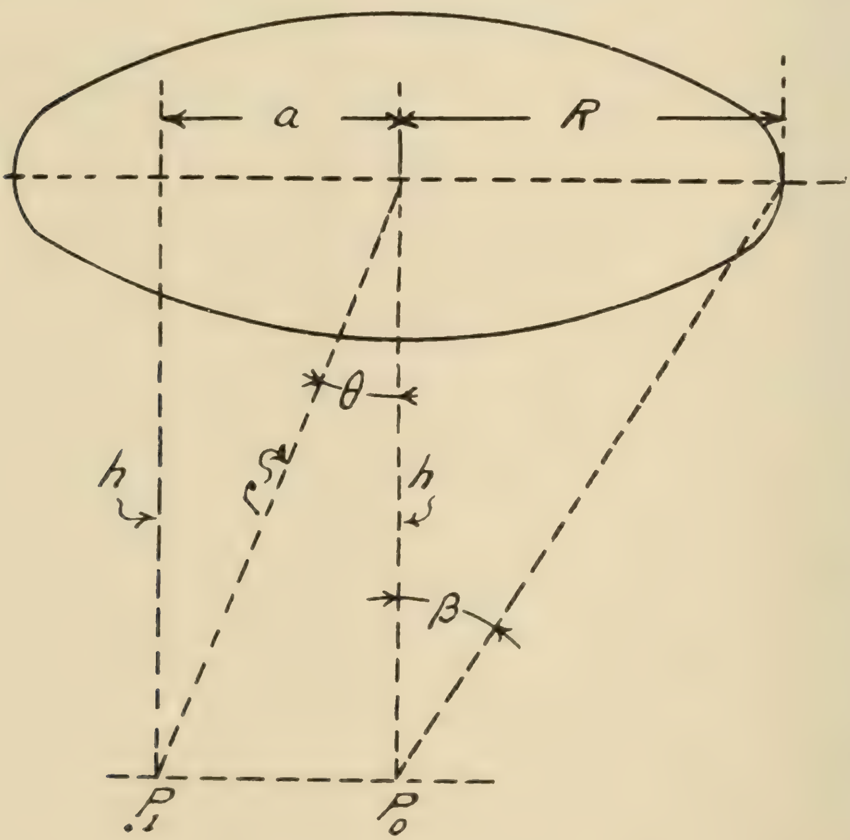


Fig. 2.

value of I on both sides of the screen is equal, whereas, mathe-

[1] v. Steinmetz, "Light and Radiation," p. 256.

matically, the direction normal to the screen is tangent to an equipotential surface and hence I is zero.

Since in the case under consideration we are seeking an expression for I normal to a screen placed parallel to the source plane, the components of intensity due to the infinitesimal portions of the source combine vectorially to produce a true resultant intensity, which may be found from the expression for V by (9).

We desire to find solutions of (8) dependent on r and θ only. Such solutions are of the form $r^m P_m(\cos\theta)$, where $P_m(\cos\theta)$ is a function of θ only. The general solution of (8), for any point, P_1, (Fig. 2) is, therefore,

$$V_{P_1} = \Sigma A_m r^m P_m(\cos\theta), \tag{10}$$

where A_m is an arbitrary constant. The value of r is of course determined by the co-ordinates of the point in question. Hence if keeping r constant we can find some point on the spherical surface determined by the extremity of r, at which the value of V is determined, the value of A_m can also be determined and our problem will be solved. Such an expression can be found for the point P_0 where, by (1)

$$I_{P_0} = \pi i \sin^2\beta = \pi i \frac{R^2}{(R^2 + r^2)}.$$

Or, if we write $\pi i R^2 = F$,

$$I_{P_0} = \frac{F}{R^2 + r^2}. \tag{11}$$

Now by (9)

$$I_{P_0} = -\frac{\partial V_{P_0}}{\partial h},$$

whence, since, in this case $r=h$,

$$V_{P_0} = -F\left(\frac{1}{R}\tan^{-1}\frac{h}{R} + C\right) = \frac{F}{R}\left(\frac{\pi}{2} - \tan^{-1}\frac{h}{R}\right).$$

When $R>h$ we can expand (11) in ascending powers of as follows:

$$V_{P_0} = \frac{F}{R}\left(\frac{\pi}{2} - \frac{h}{R} + \frac{h^3}{3R^3} - \frac{h^5}{5R^5} + \cdots\right). \tag{12}$$

To find a similar value of V_{P_0} when $h > R$ we have to expand (11) thus, remembering that $h = r$,

$$I_{P_0} = \frac{F}{h^2}\left(1 - \frac{R^2}{h^2} + \frac{R^4}{h^4} - \frac{R^6}{h^6} + \dots\right).$$

whence, by (9)

$$V_{P_0} = \frac{F}{R}\left(\frac{R}{h} - \frac{R^3}{3h^3} + \frac{R^5}{5h^5} - \frac{R^7}{7h^7} + \dots\right). \qquad (13)$$

Picking out the constants from (12) and (13) and substituting in (10) we have, since the values of A_m are by symmetry, the same for any value of V,

$$V_{P_1} = \frac{F}{R}\left[\frac{\pi}{2} - \frac{r}{R}P_1(\cos\theta) + \frac{1}{3}\frac{r^3}{R^3}P_3(\cos\theta) - \frac{1}{5}\frac{r^5}{R^5}P_5(\cos\theta) + \dots\right]. \qquad (14)$$

when $r < R$, $\theta < \frac{\pi}{2}$, and

$$V_{P_1} = \frac{F}{R}\left[\frac{R}{r} - \frac{1}{3}\frac{R^3}{r^3}P_2(\cos\theta) + \frac{1}{5}\frac{R^5}{r^5}P_4(\cos\theta) - \dots\right] \qquad (15)$$

when $r > R$.

Remembering that $r = (h^2 + a^2)^{1/2}$ and differentiating (14) and (15) with respect to h, we have, by (9),

$$I_{P_1} = -\frac{F}{R}\left[-\frac{h}{Rr}P_1(\cos\theta) + \frac{hr}{R^3}P_3(\cos\theta) - \frac{hr^3}{R^5}P_5(\cos\theta) + \dots\right]$$

$$= \frac{F}{R^2}\left[\frac{h}{r}P_1(\cos\theta) - \frac{h}{R}\cdot\frac{r}{R}P_3(\cos\theta) + \frac{h}{R}\cdot\frac{r^3}{R^3}P_5(\cos\theta) - \dots\right] \qquad (16)$$

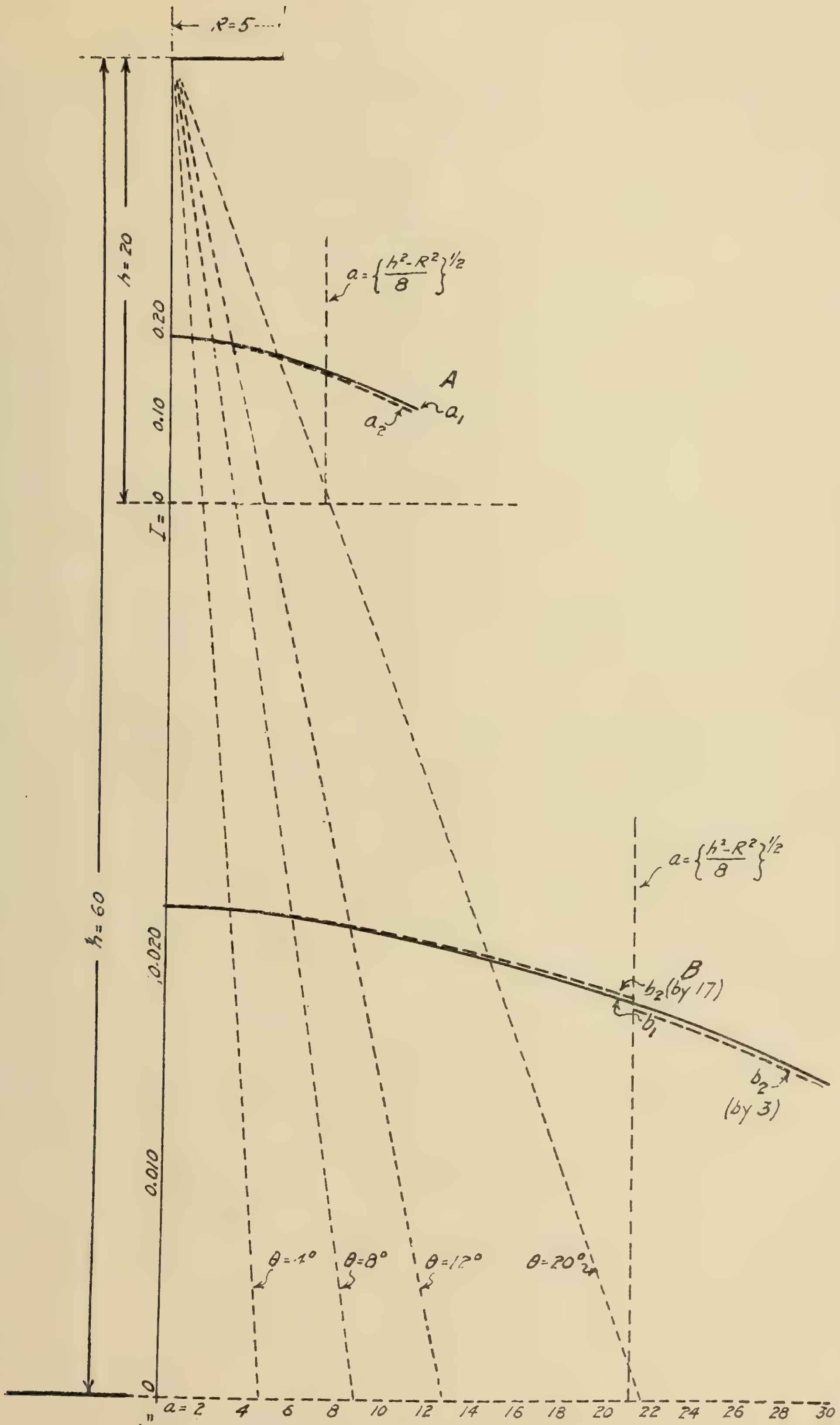
when $r < R$ and $\theta < \frac{\pi}{2}$, and

$$I_{P_1} = -\frac{F}{R}\left[-\frac{hR}{r^3} + \frac{hR^3}{r^5}P_2(\cos\theta) - \frac{hR^5}{r^7}P_4(\cos\theta) + \dots\right]$$

$$= \frac{Fh}{r^3}\left[1 - \frac{R^2}{r^2}P_2(\cos\theta) + \frac{R^4}{r^4}P_4(\cos\theta) - \dots\right] \qquad (17)$$

when $r > R$.

In (16) and (17) we have a means of checking (3) and (6) for any given case. The practical disadvantage of (16) and



R=5
h=20
0.20
0.10
I=0
$a=\left\{\frac{h^2-R^2}{8}\right\}^{1/2}$
A
a_1
a_2
h=60
0.020
0.010
B
b_2 (by 17)
b_1
b_2 (by 3)
θ=4°
θ=8°
θ=12°
θ=20°
I=0
a=2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

Fig. 3.

(17) is that the term outside the brackets and the value of r has to be computed for every point at which the illumination is required when h is constant, while in (3) and (6), a is the only variable and is always known. Furthermore, the labor of computing values of I by (16) and (17) for points over a large region is prohibitive. Let us then plot some illumination curves for a specific source.

In Fig. 3 are shown two sets of curves plotted for a source where $i=1$, $R=5$. In curves A the line a_1 is obtained by plotting values of I calculated by (6). The line a_2 is obtained by plotting values of I calculated by (17). In both cases $h=20$. Points on a_1 for values of a greater than $\left[\frac{h^2 - R^2}{8}\right]^{\frac{1}{2}}$ were obtained by the use of (3). In curves B the line b_1 is obtained by plotting values of I calculated by (6). The line b_2 is obtained by plotting values of I calculated by (17). In both cases $h=60$.[1]

There is, of course, no practical advantage in employing any of the formulas (3), (6), or (17) for computing I when $h > 10R$, since in that case the error in treating the surface source as a true point source subject to (1) and (2), page 281, is less than one per cent. Formula (3), however, enables us to extend our calculations over the region between $h=R$ and $h=10R$ without material error and without excessive tediousness in computation.

In Fig. 4 is shown a curve plotted from values of I obtained by (3) for the case $R=10$, $h=10$, $i=10$. The labor of computating this curve by (17) would be prodigious, if at all possible.

In using (3) one precaution is necessary. The tangent functions must be carefully computed for fractions of a degree. A little practice will indicate the care required in any particular case.

When the surface in question is rectangular in form we have the expression

$$I = \frac{i}{2}\left[\frac{a}{(h^2+a^2)^{\frac{1}{2}}}\tan^{-1}\frac{b}{(h^2+a^2)^{\frac{1}{2}}} + \frac{b}{(h^2+b^2)^{\frac{1}{2}}}\tan^{-1}\frac{a}{(h^2+b^2)^{\frac{1}{2}}}\right] \qquad (18)$$

[1] For tables of Zonal Harmonics see Byerly: "Spherical Harmonics," pp. 278-281.

giving the normal intensity at a point under one corner of the source and at a distance h below it. The dimensions of the

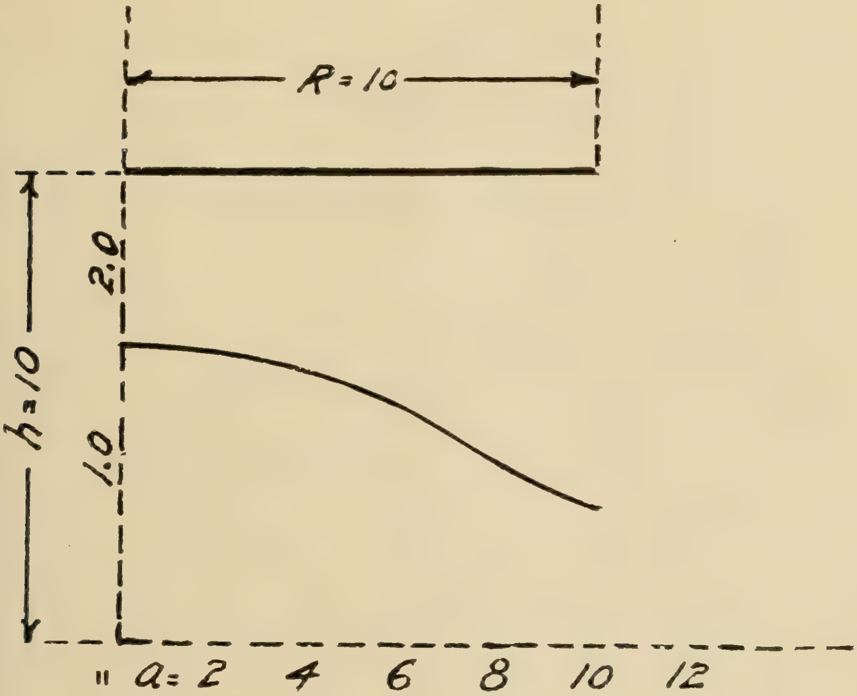


Fig. 4.

source are a and b. If the source is square, $b=a$, and (16) reduces to

$$I = i\left[\frac{a}{(h^2+a^2)^{1/2}} \tan^{-1} \frac{a}{(h^2+a^2)^{1/2}}\right]. \tag{19}$$

Formula (18) was not given correctly in the paper above mentioned. The error was, however, perfectly obvious. Formula (19) was omitted altogether.

The formulas (18) and (19), are given for a point under one corner of the source, since they are simpler and easier to remember than a formula for computing the intensity at any point under the source. However, as will be seen later, they can be used to find the intensity at any point below the source. These formulas may be put in a form suitable for rapid approximate work. Let us write $\frac{a}{(h^2+a^2)^{1/2}} = \sin\alpha$ and $\frac{b}{(h^2+b^2)^{1/2}}$ $\sin\beta$, and let us construct the angles $\tan^{-1}\sin\alpha = \rho_1$ and $\tan^{-1}\sin\beta = \rho_2$.

Then $\sin \alpha = \tan \rho_1$, and $\sin \beta = \tan \rho_2$. Putting these values in (18) and (19) we get respectively,

$$I = \frac{i}{2}\Big[\rho_1 \tan \rho_2 + \rho_2 \tan \rho_1\Big], \tag{20}$$

and

$$I = i\rho \tan \rho, \tag{21}$$

since in the latter case $\rho_1 = \rho_2 = \rho$, say.

Formulas (20) and (21) enable us to obtain values for I by constructing ρ_1 and ρ_2 or ρ, with compass and square from a scaled drawing of the source. The values of these angles can be read off by a protractor and readily reduced to circular measure.

To further illustrate the use of (18) and (19), let us plot a curve of intensities for the case where $i=1$, $h=20$, $a=5$, and $b=10$, a and b being respectively one-half of each side of a rectangular source 10 wide and 20 long. Let it be required to find the values of I for points below the longer central axis.

The value of I directly below the center of the source may be found by considering the total intensity to be four times the intensity below one corner of one-quarter the source. In this case (18) becomes

$$I = 2i\Big[\frac{a}{(h^2+a^2)^{\frac{1}{2}}} \tan^{-1}\frac{b}{(h^2+a^2)^{\frac{1}{2}}} + \frac{b}{(h^2+b^2)^{\frac{1}{2}}} \tan^{-1}\frac{a}{(h^2+b^2)^{\frac{1}{2}}}\Big], \tag{22}$$

which reduces to πi when $h=0$.
Substituting we get

$$I = 2\Big[\frac{5}{(400+25)^{\frac{1}{2}}} \tan^{-1}\frac{10}{(400+25)^{\frac{1}{2}}} + \frac{10}{(400+100)^{\frac{1}{2}}} \tan^{-1}\frac{5}{(400+100)^{\frac{1}{2}}}\Big].$$

$$= 2[0.2425 \times 0.4520 + 0.4472 \times 0.2199]$$

$$= 0.4150.$$

The value of I directly below one end of the axis may be con-

sidered as twice the value found below one corner of half the source divided along the b axis. In this case (18) becomes

$$I = i\left[\frac{a}{(h^2+a^2)^{\frac{1}{2}}} \tan^{-1} \frac{B}{(h^2+a^2)^{\frac{1}{2}}} + \frac{B}{(h^2+B^2)^{\frac{1}{2}}} \tan^{-1} \frac{a}{(h^2+B_2)^{\frac{1}{2}}}\right] \qquad (23)$$

where $B = 2b$.

Substituting, we get

$$I = \left[\frac{5}{(400+25)^{\frac{1}{2}}} \tan^{-1} \frac{20}{(400+25)^{\frac{1}{2}}} + \frac{20}{(400+400)^{\frac{1}{2}}} \tan^{-1} \frac{5}{(400+400)^{\frac{1}{2}}}\right]$$

$$= 0.2425 \tan^{-1} 0.9700 + 0.7072 \tan^{-1} 0.1768$$

$$\doteq 0.3100.$$

To illustrate the method completely it will only be necessary to compute I for one intermediate point. Divide the b axis, drawn from the center of the source perpendicular to the side a, into two equal parts. Let the point in question be below this dividing point. We then have to treat that part of the source lying on each side of a line drawn through this point perpendicular to the b axis independently and add the results.

We then have, by (23),

$$I_1 = i\left[\frac{5}{(20^2+5^2)^{\frac{1}{2}}} \tan^{-1} \frac{15}{(20^2+5^2)^{\frac{1}{2}}} + \frac{15}{(20^2+15^2)^{\frac{1}{2}}} \tan^{-1} \frac{5}{(20^2+15^2)^{\frac{1}{2}}}\right] \qquad (A)$$

and

$$I_2 = i\left[\frac{5}{(20^2+5^2)^{\frac{1}{2}}} \tan^{-1} \frac{5}{(20^2+5^2)^{\frac{1}{2}}} + \frac{5}{(20^2+5^2)^{\frac{1}{2}}} \tan^{-1} \frac{5}{(20^2+5^2)^{\frac{1}{2}}}\right] \qquad (B)$$

since in (A), $a=5$, $B=10+5=15$, and in (B) $a=5$, $B=5$. Reducing, we get

$$I = I_1 + I_2 = 0.2517 + 0.1151 = 0.3668.$$

In the case where the point at which the value of is required lies outside the source boundary formulas (18), (19), (22) and (23) may still be used by first making the calculations as though the source were extended until the point lies under its boundary and deducting from this a value computed for the assumed extension of the source. Of course separate formulas may be written down for each case, but such formulas merely indicate the various applications of (18) given above.

Formulas may be deduced either in terms of elliptic integrals or in terms of harmonic functions for the case where the surface is elliptic in form. Such formulas, however, would be laborious in practical application and are unnecessary since the error in considering such sources as equivalent to rectangular or circular sources of the same area may be made negligible by a suitable selection of the dimensions of the equivalent source. Where the major axis of the ellipse is not much greater than the minor axis an equivalent circular source may be used. Where the difference between the axes is considerable, an equivalent rectangular source may be used.

Another useful case is that dealing with the component of I parallel to the plane of the source at any point below a rectangular source such as would occur in the artificial illumination of a room by means of sashes or a frieze of suitable glass let into the walls.

If, as before, a and b are dimensions of half the source divided along the b axis, then the apparent intensity at point distant h. in a direction perpendicular to the plane of the source from any point of the b axis, prolonged, (Fig. 5) is

$$\mathrm{I} = i\left[\frac{h}{q}\tan^{-1}\frac{a}{q} - \frac{h}{p}\tan^{-1}\frac{a}{p}\right] \qquad (24)$$

where q is the distance from the point in question to the nearest point at which the b axis cuts the source boundary, and p is the corresponding distance to the far extremity of the b axis.

Formula (24) may be put in a form similar to (18) giving I for that part of the source lying on one side of the b axis. It is

$$I = \frac{i}{2}\left[\frac{h}{q}\tan^{-1}\frac{a}{q} - \frac{h}{p}\tan^{-1}\frac{a}{p}\right]. \qquad (25)$$

When $h=q$ we have from (25)

$$I = \frac{i}{2}\left[\tan^{-1}\frac{a}{h} - \frac{h}{p}\tan^{-1}\frac{a}{p}\right], \qquad (26)$$

and formulas (25) and (26) may be used in a manner similar

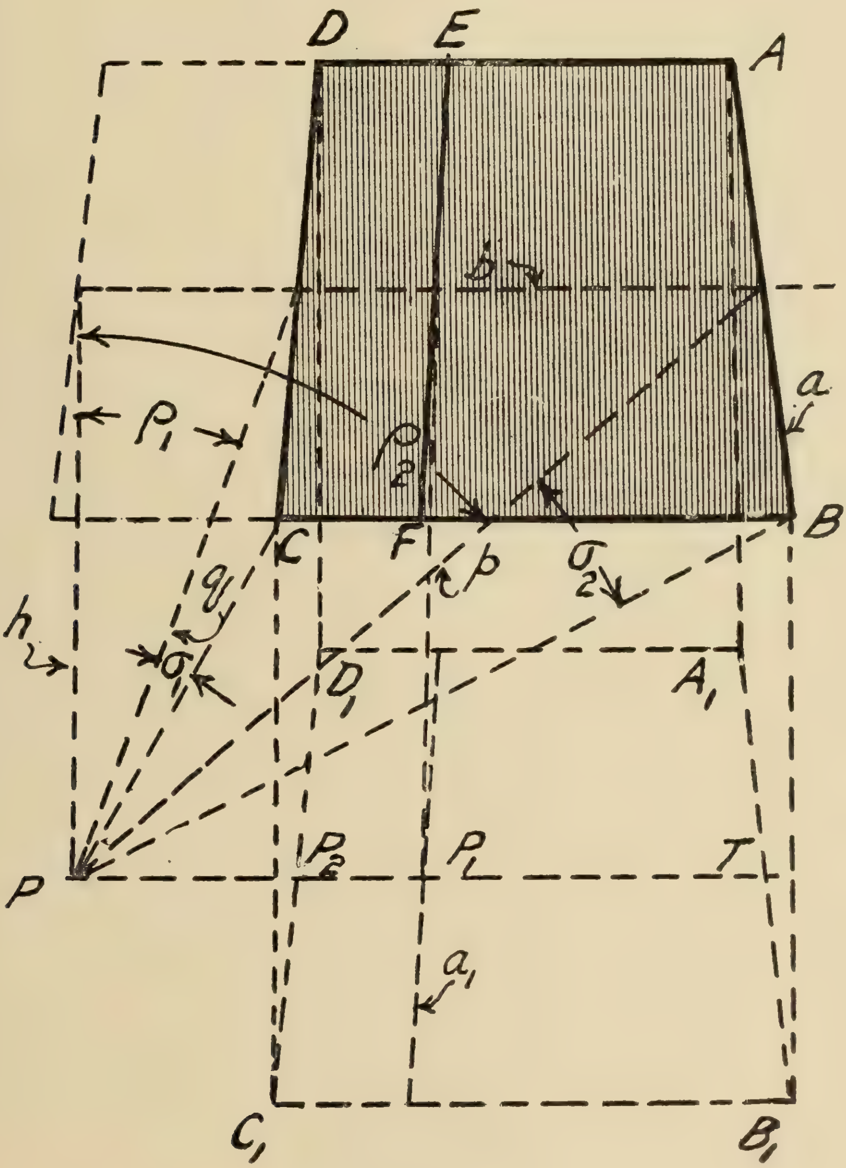


Fig. 5.

to that explained above for the case dealing with the normal apparent intensity, to calculate the intensity in a direction parallel

to the plane of the source, at any point not in the plane of the source.

Formulas (25) and (26) may also be put in a form similar to (20) suitable for graphical work. Let us write $\frac{h}{q} = \cos \rho_1$, and $\frac{h}{p} = \cos \rho_2$. Then let $\tan^{-1} \frac{a}{q} = \sigma_1$, and $\tan^{-1} \frac{a}{p} = \sigma_2$. We then have, respectively,

$$I = \frac{i}{2}\left[\sigma_1 \cos \rho_1 - \sigma_2 \cos \rho_2 \right], \tag{27}$$

and

$$I = \frac{i}{2}\left[\sigma_1 - \sigma_2 \cos \rho_2 \right]. \tag{28}$$

It should be noted, however, that when P is within the right projection of the source boundary as at P_1, then only that part of the source lying in the direction P_1T from the line a_1, that is ABEF, contributes to the effective intensity in the direction P_1T. The part of the source CDEF would only serve to illuminate the back of a screen at P_1. To obtain the maximum illumination on the screen in the direction P_1T, the point P must be taken on the right projection of the boundary $A_1B_1C_1D_1$ as at P_2.

To complete, for our purposes, the discussion, we may repeat the statement made in my paper; viz., that sources of any shape, such as hemispherical, semi-ellipsoidal, or semi-cylindrical may be treated as plane suurface sources having an area equal to the aperture of the actual source and a flux per unit area equal to the flux per unit area of the actual source.

In the discussion that has arisen over the various proposed methods of calculating the intensity of light flux, of which the above are samples, it has been stated in effect that it is the business of "the scientist" to discuss the matter completely and that it is for the engineer to appropriate and use so much of the results obtained by "the scientist" as he needs for his own practical work. Unfortunately "the scientist" has given us no thorough-going discussion of finite surface light sources; and, so far as I know, very little attention has been paid to finite surface

radiators of any kind except in a few instances generally useless for our work.

In my practice I have found urgent necessity for the use of some formulas of the nature outlined above. The paper heretofore mentioned and this article are the outcome of that necessity—they make the attempt to get at the needed results with as little "scientific" circumlocution as need be. There may be a number of interesting, and doubtlessly fruitful by-paths which have remained unnoticed in the course of this work.

A paper presented at a meeting of the New York Section of the Illuminating Engineering Society, New York, April 14, 1910.

THE RELATION OF FIXTURE DESIGN TO MODERN ILLUMINATING ENGINEERING PRACTICE.

BY L. R. HOPTON AND H. E. WATKINS.

In looking over the TRANSACTIONS of our Society there are to be found a number of papers that have been presented from time to time dealing in some way with the question of the proper design of lighting fixtures. The subject of residence, store and school lighting has been ably presented by several members, the question of the proper accessories to be used in enhancing the efficiency of various types of lighting structures has been frequently discussed, and the matter of the relation of modern fixture design to certain assumed standards of construction as laid down by progressive illuminating engineers has been given careful attention in either our TRANSACTIONS or other engineering literature.

Our first inclination in preparing this paper was to consider almost wholly the matter of fixture design from the standpoint of construction, and to present to you fully our views as to the extent to which the fixture designer may embody in his constructions the apparatus and illuminants that are associated in our minds with efficiency and economy. While we have given these matters some thought in this paper it seemed to us better, especially in view of the diversity of opinion that exists among the members of this profession regarding the importance or non-importance of certain considerations in the matter of fixture design, to handle this subject in the broadest possible way, and to take up carefully certain matters affecting the design of lighting fixtures that have been left almost untouched in our TRANSACTIONS.

Were an outsider asked to define the relation of illuminating engineering to architecture, or, to be more concise, to define the relation of modern illuminating engineering to architectural principles, and were he to attempt to find his answer by searching the literature of our profession, he would

be at a loss to shape his reply. Were he to attempt to narrow his definition to the relation of fixture design to modern illuminating engineering practice, he would still be unable to formulate a definite opinion. We are told by one writer,

> The great curse of the engineering profession is the inbred belief that efficiency is the only thing that counts.

And by another,

> The illuminating engineer must enforce the recognition of his figures and calculations, disregarding every other limitation but practicability, efficiency and economy.

We also read:

> The illuminating engineer who considers only the scientifically practical side of the profession is necessarily doomed to ultimate failure, for he will not be able to obtain the recognition that the importance of his work deserves.

And:

> Engineering has no essential connection with aesthetics in any form; the sooner the illuminating engineer gets this out of his head the better.

Considering such diametrically opposed ideas as these, it seems almost hopeless to formulate a satisfactory definition that shall answer the implied question contained in the title of this paper. The various writers whom we have quoted are certainly honest in their beliefs, but they hold pronounced differences of opinion on what we consider to be a most important matter.

One of the most comprehensive papers to which we have had the pleasure of listening was that presented in December, 1907, by Bassett Jones, Jr., on "The Relation of Architectural Principles to Illuminating Engineering Practice." No one interested in the field of illumination can read this paper carefully without at least feeling that there should be a close bond of cooperation between the architect who has planned and the illuminating engineer who is called upon to assist him in the proper lighting of the structure.

So much has been said along these lines by those most competent to speak that our remarks in this direction are intended only to call to mind again and to emphasize again the fact that the illuminating engineer and fixture designer must appreciate and understand the architect's view point, or they cannot successfully handle the problems that are set before them. It is not

given to many of us to discover new lighting media nor to revolutionize any system of lighting. Few of us will ever hang our names in the hall of illuminating engineering fame, but to all of us is given the task of improving the condition of our fellow men by applying the knowledge that we have gained by study and observation in our particular field, and of leaving behind us a record of achievement that shall guide in a measure those that are to take up this work where our hands have left it.

We do not propose to advance any new theories nor to settle forever the question as to the function of an illuminating engineer in connection with the problem of fixture design. We shall try in a simple and logical manner to give our views on this subject and the results of our daily experience.

Our belief is that many of the differences of opinion among illuminating engineers regarding the proper design of lighting fixtures come from a misconception of the particular locations and uses of the fixtures in question. For some classes of lighting fixtures the illuminating engineer can carry his ideas of efficiency and construction as far as he wills. The fixture designer and architect will gladly modify their design so that the instrument of lighting will be, above all else, a scientifically designed engineering apparatus. The latest lamps and reflectors can be adopted without question, and the success or failure of the fixture may be measured largely by the illuminometer, wattmeter, or any other meter that may be required to measure engineering results. In other cases the designs may be greatly modified by consideration of efficiency and economy, but this modification must be carried out intelligently by those who are ever closely in touch with the architectural limitations.

In still other cases the artistic qualities of the design must be uppermost. The fixtures must be in perfect architectural harmony with their surroundings, and nothing radically new in the way of lighting as affecting the design can properly be considered. These cases call for the greatest skill in conserving the period of the architecture and in designing harmonious and appropriate lighting fixtures.

It is our purpose to show to what extent considerations of efficiency and economy may enter into various designs, but we

feel that this cannot be done without directing attention to the basic principles underlying the most important styles of architecture. Much has been said regarding period and the necessity of harmony in design, but there seems to be little information available to aid the illuminating engineer as a definite guide regarding how far he may properly go in introducing new methods of lighting into buildings which are designed with a well defined "period" of architecture. As Mr. Jones has said:

> The illuminating engineer who imagines that he can introduce anything radically new into the illumination of buildings possessing historic feeling is doomed to disappointment.

Bear in mind that this means anything "radically new," and buildings possessing "historic feeling." No more true or concise statement could be made, but it is permissible and desirable, to introduce modern methods into the lighting of public buildings just so far as the architect's individual treatment of the style of his architecture and the departure from strict historical precedent will permit. We make this statement now lest some might think that the rest of our paper were to be devoted to the advocating of a policy of abandonment of all new methods or means of lighting.

The development of the lighting structure affords a fascinating study; that is, the ornamental and structural development of lighting fixtures with relation to the means or appliances for lighting, the architectural period and various other considerations. As we study this history, we find the same appliance for lighting handled in different ways and ornamented in different manners, and the quantity and quality of the light also altered to harmonize with the changing conditions of architecture.

We might generalize further, but to illustrate the matter more clearly we will briefly consider a few of the more distinct periods in architecture and the relations of fixture design and lighting methods to the various periods under consideration.

From the dim shadows of ages past we gain new light. One of the earliest periods that finds reproduction to-day, and that therefore calls for artificial lighting, is the Egyptian. As to the instrument of lighting during this period there is little doubt.

Search as we may in the oldest Egyptian tombs, amongst the remains of early Greece and Rome or recorded in the early histories of the Hindoo and Chinese, one form is uppermost—the lamp.

Aside from being an instrument of lighting, the lamp was frequently an object of worship, and as signifying the immortality of the soul it was often kept burning in the tombs of the dead. As a subject of worship, the lamp was therefore a subject of beauty, and by its construction an object of art, as well as a source, very poor, to be sure, of light.

In this period, therefore, the fixture designer should work with the lamp as his "motif" and should combine with the beautiful in ornament a soft quality of light that will enhance the feeling of shadow and mysticism that the architecture of this period should call forth. Too brilliant a light would not only absolutely destroy the charm of the architecture of the period, but would also destroy the beauty of the lighting instrument as a work of art.

Fortunately the reproductions of Egyptian art are rare, and are usually so carefully and correctly carried out as reproductions that there is little danger of the illuminating engineer being called upon to use his talents in modernizing any system of lighting. Fig. 1 illustrates a lighting fixture designed for this period and one making use of the modern illuminant electricity.

What has been said about the lamp in connection with the Egyptian period may also be said with regard to the Greek period, and, in addition, there appears the use of the torch effect for exterior lighting. Here, again, the lamps were highly ornamented, while their tripod torches were usually beautiful works of art.

There is no dispute or question as to the standing of Greek architecture previous to 300 B.C. as the most perfect that decorative art has produced. It is the basis of almost all periods of decoration and architecture that followed. As we turn the pages of the history of ornamental art, we see designers and architects gaining their inspiration from the beauty and simplicity of the Greek, but so stamping their individuality in their work that

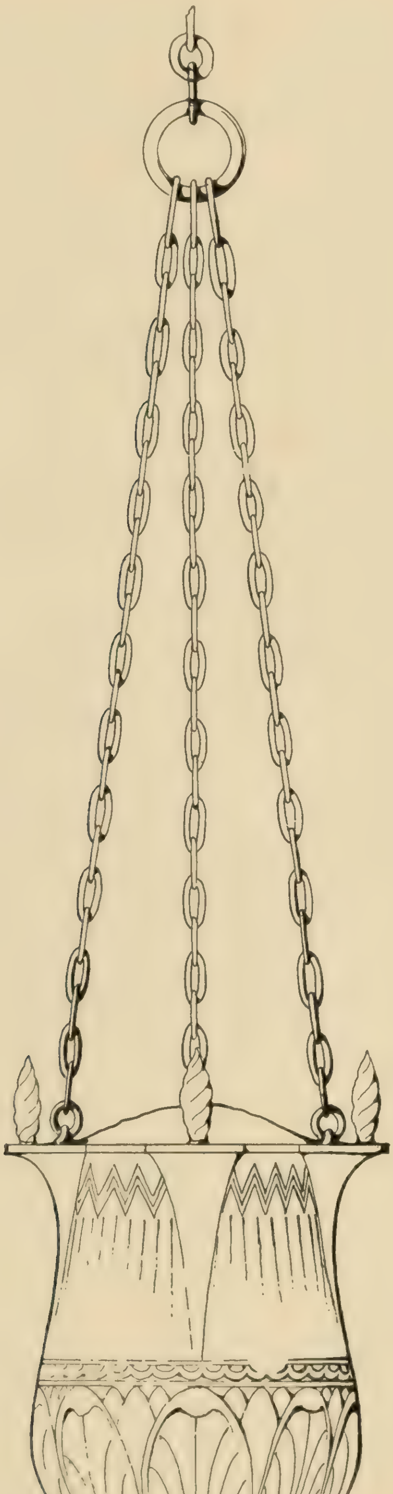


Fig. 1.

they successively bring new styles or periods into being. Some of the more important of these will be spoken of later.

Owing to the fact that Greek is a living period and is being used by architects to-day as their inspiration for some of our finest structures, the lighting of Greek architecture is most important.

Let us repeat that the illuminating engineer may be guided in planning and designing his light sources by the extent to which the Greek has been "modernized" by the architect or designer of the building to be lighted. If the structure is a reproduction, or is altered slightly from the simple form and ornament of the original Greek, the lighting instrument must be designed to use the desired modern illuminant, but to use it in a form and of a quality to harmonize with the architecture. The fixtures may have the lamp or torch motif and the light should be soft. of a yellow tone and should not destroy by its brightness the beauty of the appliance as a work of art. Fig. 2 shows a lighting fixture that preserves the original form of the lighting instrument, modernized as far as possible to use the modern illuminant, electricity.

Where the lighting of buildings reproducing some Greek masterpiece is required, the designer must design along these lines, and the illuminating engineer can do little or nothing to direct the form of the lighting fixtures. Such cases are rare, however, and the architect of to-day, working under the influence and with a love for the "orders" will modernize his structure and will make use of the beautiful Greek ornament and proportion, but will produce a structure modern in its equipment and use. In such cases the designer and illuminating engineer may safely depart from the traditional forms and may bring into being for use in the building a line of lighting instruments distinctively Greek in line and ornament, but as distinct from the original Greek lighting appliance as is the building itself from any recorded or preserved Greek masterpiece of antiquity. Fig. 3 illustrates a fixture that has been designed and installed and which typifies fairly well the treatment that may be given.

In the design of a modern office or other public building, the architect may make use only of the ornament of this period to

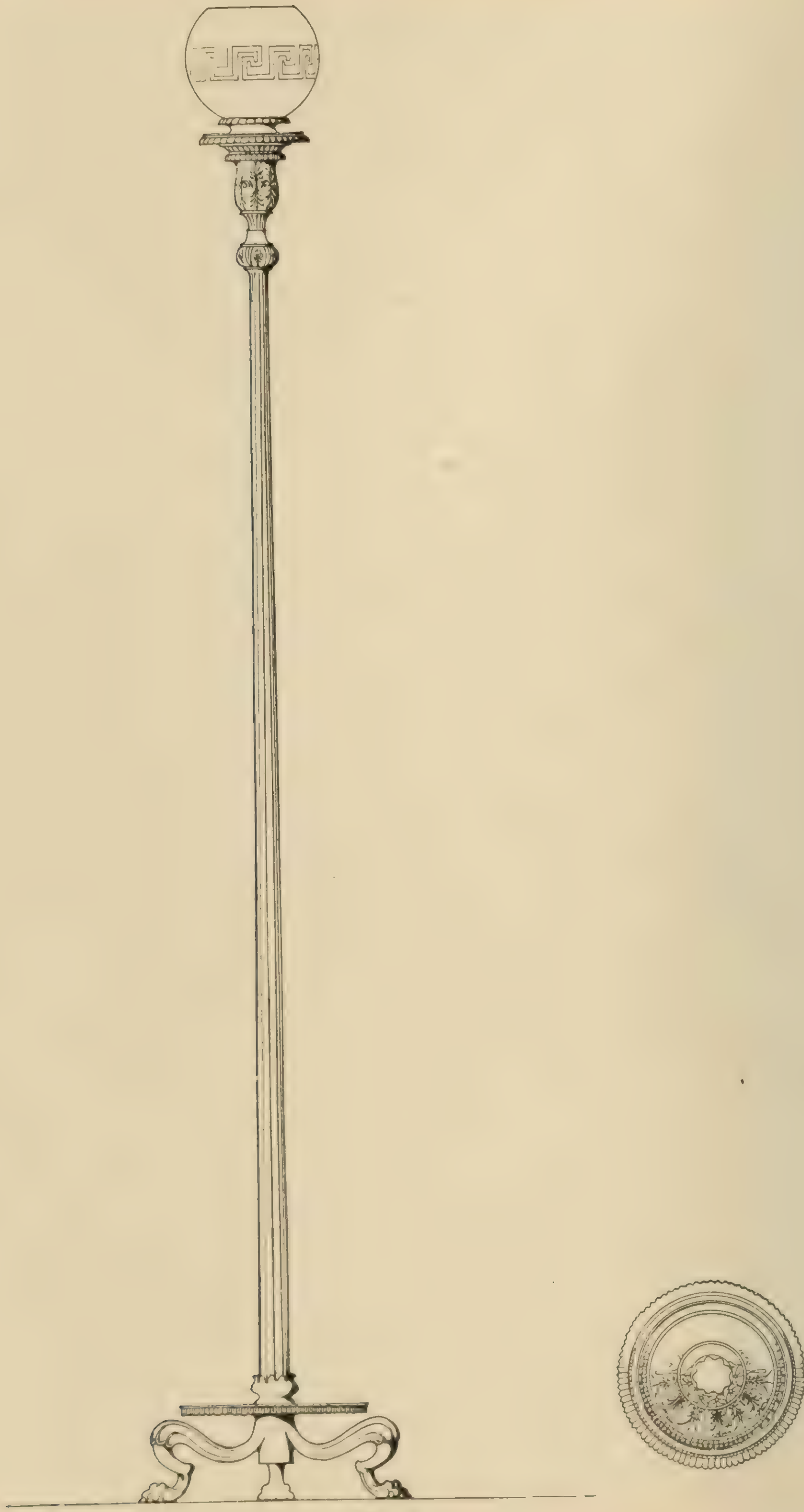


Fig. 2.

embellish his structure. His work is modern and the fixtures may be correspondingly modern with Greek ornamentation. Fig.

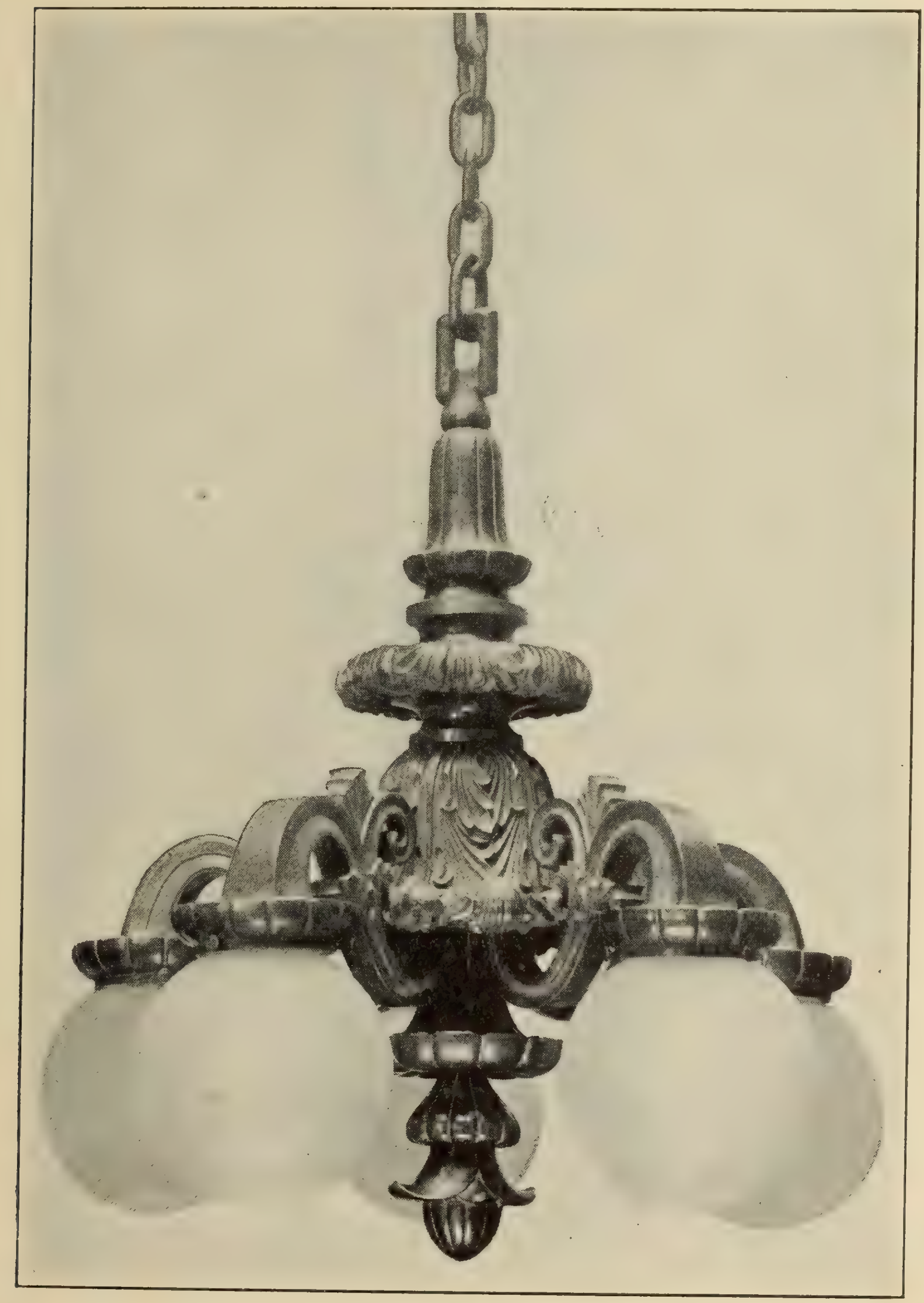


Fig 3.

4 illustrates a construction of this character in which the lights are arranged and appliances used that satisfy more readily

Fig. 4.

the illuminating engineer's desire to obtain modern and efficient illumination.

As we depart from the original forms of Greek lighting structures and modernize the designs, so we may in our design consider the use of any appliances such as reflectors or tungsten lamps that will increase the efficiency. Our care must be, however, that the quality of the light is in harmony, and the quantity not too great to suit the surroundings nor absolutely to destroy the value of the fixtures as objects of ornament.

Did space permit, we should like to deal with the Roman architecture, showing the combining of Greek simplicity with Roman magnificence. During the grandeur of the Roman Empire, between 50 B.C. and about 350 A.D., the design of lighting instruments changed more in ornament than in form. The lamp and torch were the appliances generally used and were objects of art, beautifully proportioned and executed.

From the Roman period to the modern Italian is a long step. We shall deal later in the paper with the Renaissance, and speak of the influences that affected alike the French and the Italian; influences that produced a style of architecture and ornament that is being used to-day in modern structures. The following two illustrations will serve to show the types of fixtures that may be designed with the beautiful lines and ornament of this period. Fig. 5 illustrates a fixture designed for modern usage, but with a construction to harmonize with a carefully executed architectural interior.

Fig. 6 is a fixture designed in this period of work that has been "modernized" to a greater degree and is one that still retains the beauty of Italian line and ornament.

The Romanesque of Northern Italy, *i.e.,* in and around the plains of Lombardy, had its rise in the 9th century, although little of moment that survives was built until a century or two later.

Milan was the center of architectural advance in Northern Italy from the 9th to the 12th century, and it was there, and in the neighboring town, that Italian Romanesque was first fully developed. One of the most interesting buildings of this period is the Church of Ambrogio in Milan. The light source in many of the buildings of this period was very meagre, but we may note

Fig. 5.

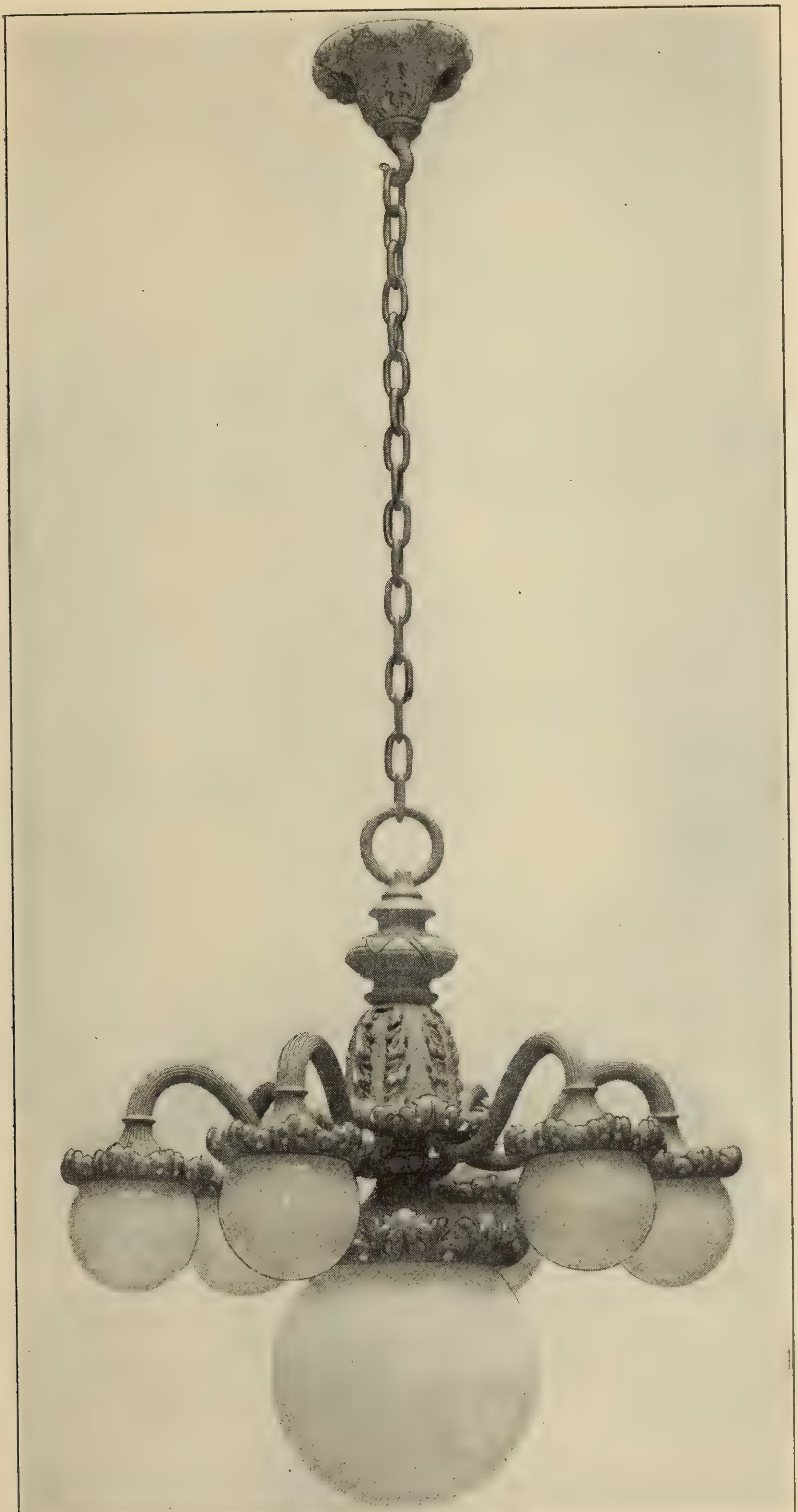


Fig. 6.

here that in the Church of S. Zeno, Verona, built in the first half of the 12th century, we to-day find pendant from the arches on cord and tassel beautifully carved lamps with branched arms for candles.

Romanesque architecture is rarely produced in modern structures and therefore there is little occasion to consider the problem of illumination. It is worth noting, however, that about this time began the development of the pendant fixture with branched arms, forming a group of small illuminants. The ornament of the Romanesque period is sometimes put to modern uses, and Fig. 7 shows a fixture designed to harmonize with this period of ornamental treatment.

Most French writers claim that the birth of Gothic, and by Gothic is understood pointed arches, ribbed vaulting and flying buttresses combined with a new system of moulding and fresh feeling in carvings, took place in the Isle de France, and from there spread outside. To some extent they are right, but properly speaking, Gothic art had no birth. What is called the birth of Gothic was but the coming age of Romanesque, and that the celebration of this took place solely in one particular part of France is open to question. There is so little difference in the dates between the early examples scattered about the country that it is permissible to conclude that the movement was a wide one, and in many countries we have monuments reared in evidence of this sublime art which words fail to describe—a great Gothic cathedral, for instance, sums up so much of history, and in the language of one of our great writers:

> It has cost so much in faith and toil, in blood and folly, in saintly abnegation; it has sheltered such a long succession of lives, given collective voice to so many inarticulate and contradictory cravings, seen so much that was sublime and terrible, pitiful and grotesque, that it is like some mysteriously preserved ancestor of the human race grown sedentary and throned in stony contemplation before whom the fleeting generations come and go. Reverence is the most precious emotion that such a building inspires, reverence for the accumulated experiences of the past; readiness to puzzle out their meaning, unwillingness to disturb rashly results so powerfully willed, so laboriously arrived at; the desire in short to keep intact as many links as possible between yesterday and tomorrow; to lose in the act of new experiment the least that may be of the long rich heritage of human experience.

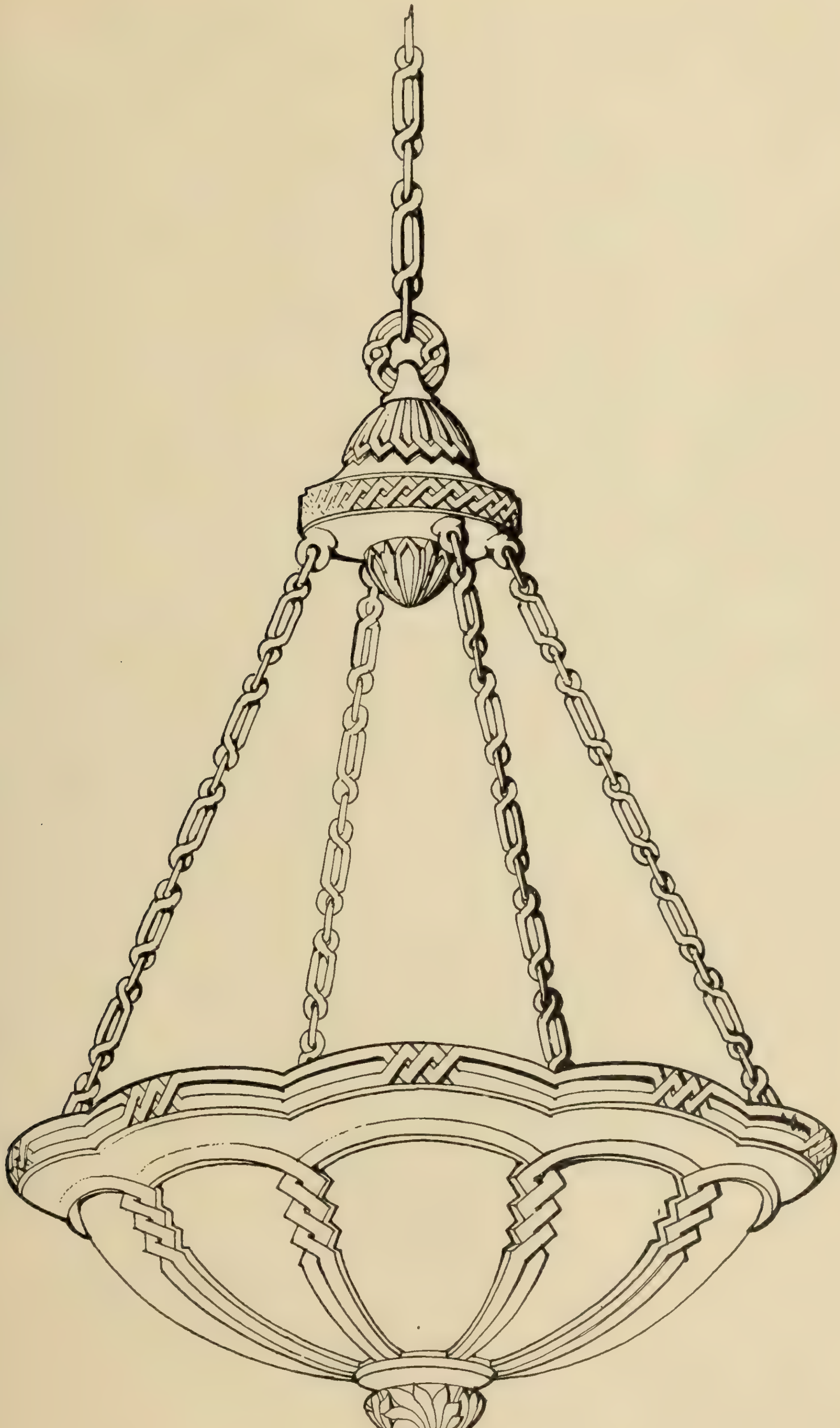


Fig. 7.

This at any rate might seem to be the cathedral's word to the traveller from a land which has undertaken to get on without a past. No wonder such monuments have silenced all competitors. Even our more modern structures, where we have endeavored in so small a way to reproduce somewhat of the grandeur of ages gone, we should hesitate to do anything in contradiction or introduce any chord or note that would destroy the harmony or in any way the reverence that these old masterpieces have always inspired.

So we find the lighting of modern Gothic architecture being the problem principally of lighting edifices of worship is exceedingly difficult. Little in the lighting of old Gothic masterpieces is of assistance, as they were either not lighted at all artificially or at best by a form of corona bearing candles, and we might mention here that in the cathedral of Notre Dame, Paris, we find to-day pendant from the high arches on slender cords beautifully wrought lamps, with branched arms in double tiers for candles.

A simple and dignified form of a modern electric pendant, treated in Gothic ornament and dedicated to ecclesiastical usage, is shown in Fig. 8. In this case the distribution of light is excellent, and if the lamps are not too bright the effect is satisfactory from every standpoint.

In Fig. 9 is shown a type of chandelier in which the Gothic ornament has been used, but which was designed for residential use.

Up to now the periods of architecture that we have mentioned are those which concern the fixture designer and illuminating engineer principally in the lighting of public buildings and almost to no extent in the lighting of the home. As we consider the French architecture and ornament through its development, we must study this with the problem of residence lighting in our minds as well as that of public buildings.

Passing on to the Renaissance, we find that on the north of the Alps the Renaissance had not the same meaning that it had in Italy and in France where its influence was first felt. The art naturally assumed a different character. The term Renaissance is not, in fact, properly applicable here, for the French

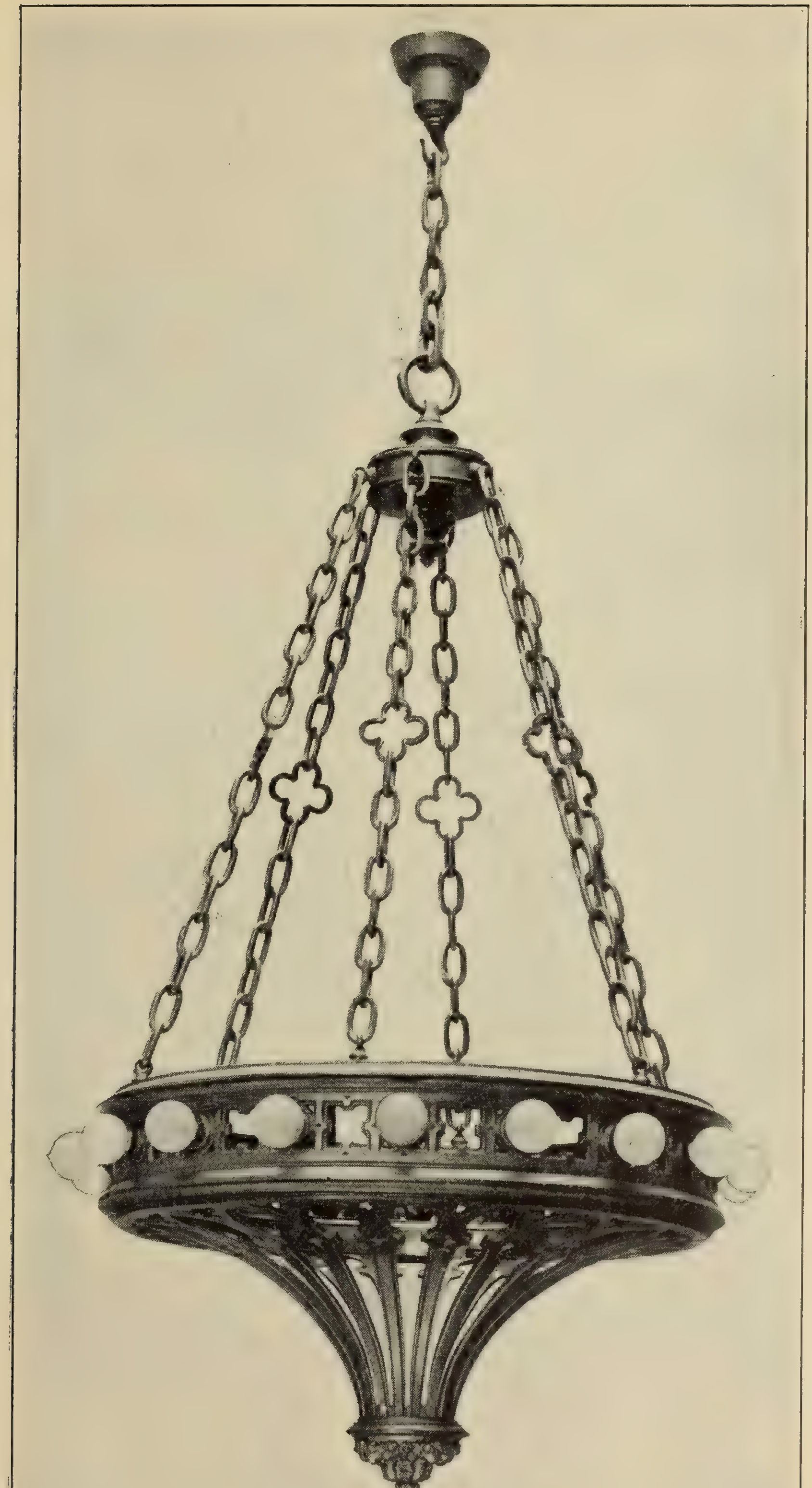


Fig. 8.

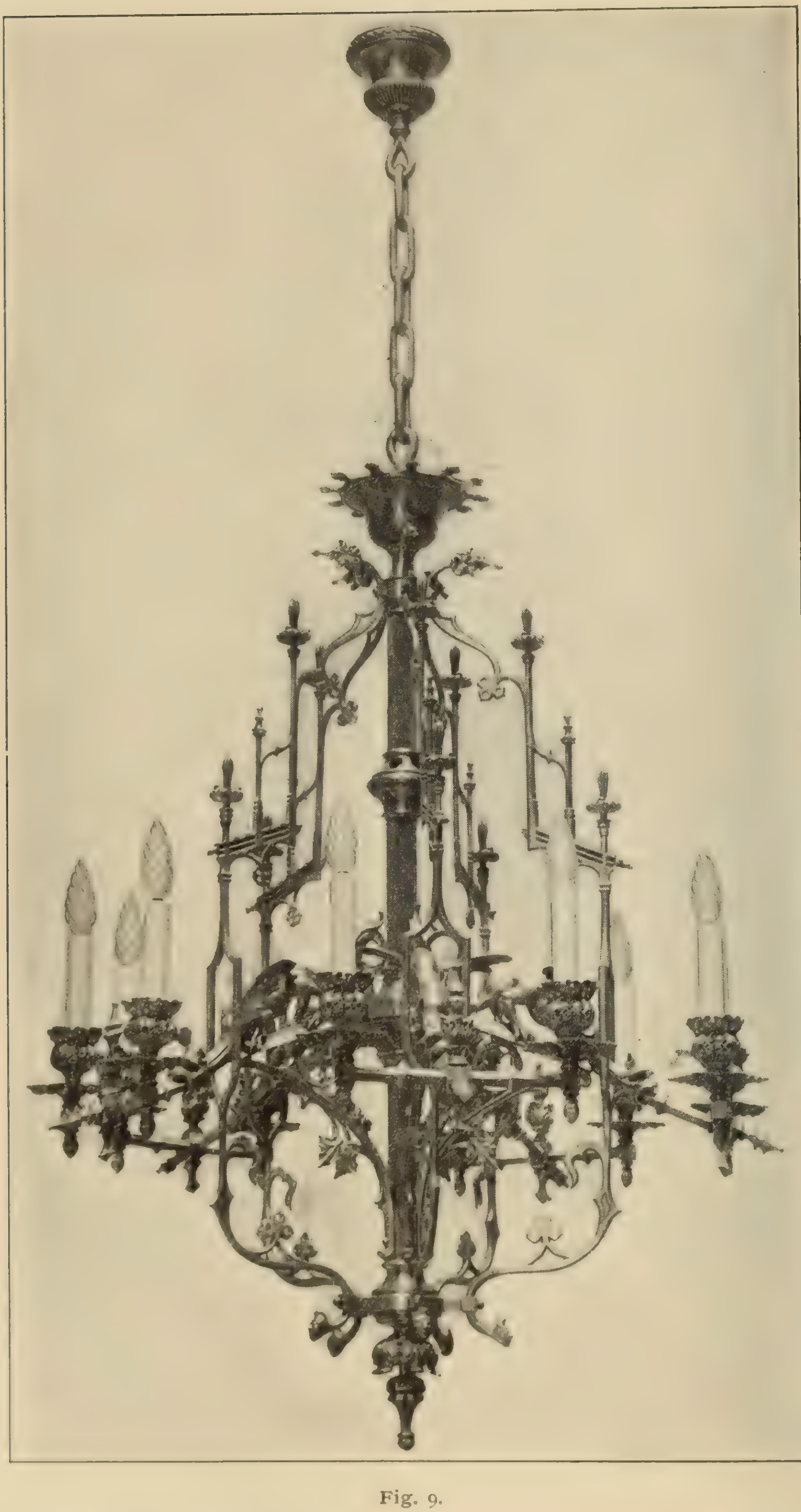


Fig. 9.

people had not a classic past and the adoption of architectural forms derived from the classic antiquity was not at all natural for them. Through the development of a noble history they had acquired and perfected a peculiar genius which had found expression in forms of art that were radically different from those of ancient times, and in now departing from the principles of this art they did violence to their own native traditions and ideals.

It has often been affirmed that French architecture was but superficially changed by the Renaissance influence and that its essential character survived beneath the Italian dress. This is not wholly true—the Italian influence did effect a fundamental change in this architecture by giving it a factitious in place of a natural character. This point has been overlooked by those who have maintained that the French artistic genius suffered no loss of integrity by yielding to the Renaissance movement, but it must not be forgotten that the native art had lost its best character long before ~~the Italian influence~~ supervened. The finest Gothic impulse was spent before the close of the 13th century, and the feeble spirit and florid extravagance of the Flamboyant, which now prevailed, betrayed a weakened condition of the national artistic mind which made it an easy prey to foreign innovations. Until the 16th century the Gothic style survived in its decadent forms, yet in some quarters before this time an interest in the arts of antiquity was gaining foothold, and a few Italian artists had come into France and wrought some small architectural works in the neo-classic manner, but the way appears to have been opened for the more general movement in the new direction when the French upper classes began to construct fine houses adapted to the requirements of luxurious life.

In this period we see the extended use of the candle as the source of light. We see the lighting fixtures designed in proportion and in line for the use of this illuminant, and we see the graceful harmony of the lighting structures. So firmly is this source of light associated with the design of French period fixtures that harmony requires that the designer of to-day should design his fixtures with this clearly in mind.

So frequently in fine residences we find, or did find up to a few years ago, a room or rooms planned to be French period rooms where to the minutest detail of furniture and decoration the reproduction is carried out. In such cases the real candle is frequently used, both for the soft quality and diffusion of the light and, also, to complete the reproduction. Where this is not desirable, the candle has been conventionalized and the modern

miniature lamp is used in its stead, often covered by a small silk shade.

Where the crystal type of fixture is used the designer and illuminating engineer may make freer use of the modern electric lamps, not forgetting, however, that the charm of fixtures of this character lies largely in the use of a large number of small units rather than a few powerful ones.

In the design of fixtures of the Louis XIV., XV., XVI., periods, the design is usually held closer to a conventional form than with many other forms. The type or ornamentation, the proportion of the lines, the quality and intensity of the source of light have been so recognized that any radical departure from familiar lines is dangerous. For this reason the illuminating engineer should know fully the limitation imposed by the designs of this period.

The art of France from the time of the Renaissance to the modern work of to-day has been so thoroughly written up in this country—so well and so badly reproduced in all its lights and shadows, that to discuss it here in all its varied details would not only be unnecessary, but would take more space than this paper would allow. It might be well in passing, however, to draw attention to a few of the great men whose work it is impossible to forget in connection with the lighting of the various interiors, the details of which they understood so well. The French room must at all times be considered a unit, every detail forming but a part of the entire harmonious whole. So well did the artist and architect understand this one great principle that every object, whether useful or ornamental—the table, the chair, the lamp, the candelabra, was designed by him with this special thought in view. The works of Jules Auriles, Messonier and Charles de la Fosse are among the most noted. Their exquisite feeling in the handling of the lighting instruments of the period, and their absolute knowledge of the placing of such pieces, has been too well done for us to criticise them from any standpoint. The candle became in their hands not only a light giving medium, but an object of great decorative value, and beautiful pieces in bronze were designed wholly and solely for its value from this standpoint. Lights were placed here and there singly

and in great clusters, not only for the value of the light (which to them was always most important), but also for the great value of forming a part of the harmonious whole.

With the advent of electricity, the much prized and by some the much despised, imitation candle came into use. However, it matters but little how much we dislike the imitation, as in no better way can the effect in these most beautiful interiors be retained. Even in the cut crystal pieces the glare of the electric bulb does much to destroy their value if not mellowed in some way. And so we are brought face to face with the fact that illuminating engineering can accomplish but little in the Renaissance interiors as well as those of to-day designed along these lines. In the use of French architecture and ornament in public buildings the conditions are different, and architects to-day are working with them in their individual way. As we said of the Greek architecture, the designer of the lighting structure should be guided by the architect and may move only so freely as he is allowed by the treatment of the architecture. It would require a multitude of illustrations to give an adequate presentation to the variety of beautiful designs that may be produced in connection with this period of work. We are merely showing in Fig. 10 a French bracket designed for use of candles equipped with miniature electric lamps and in Fig. 11 a type of crystal fixture so characteristic of this period of work.

As a departure from historical form but still making use of the beautiful ornament of this period Fig. 12 illustrates a pendant in which the electric lamps are used in a still more modern way. In this case the room was not strictly a "period" room, but was of a character to permit of a treatment of the fixture design as shown.

In the work of England and America, and other countries where the lamp and other mediums of light play as important a part as the candle, the order of things is somewhat changed, as is shown in the works of some prominent architects we shall mention later. It has been said that men can with difficulty originate even in a new hemisphere, but we trust that in the near future it will be in our province to show that a few good things have been brought to light in illumination in connection with decorative art

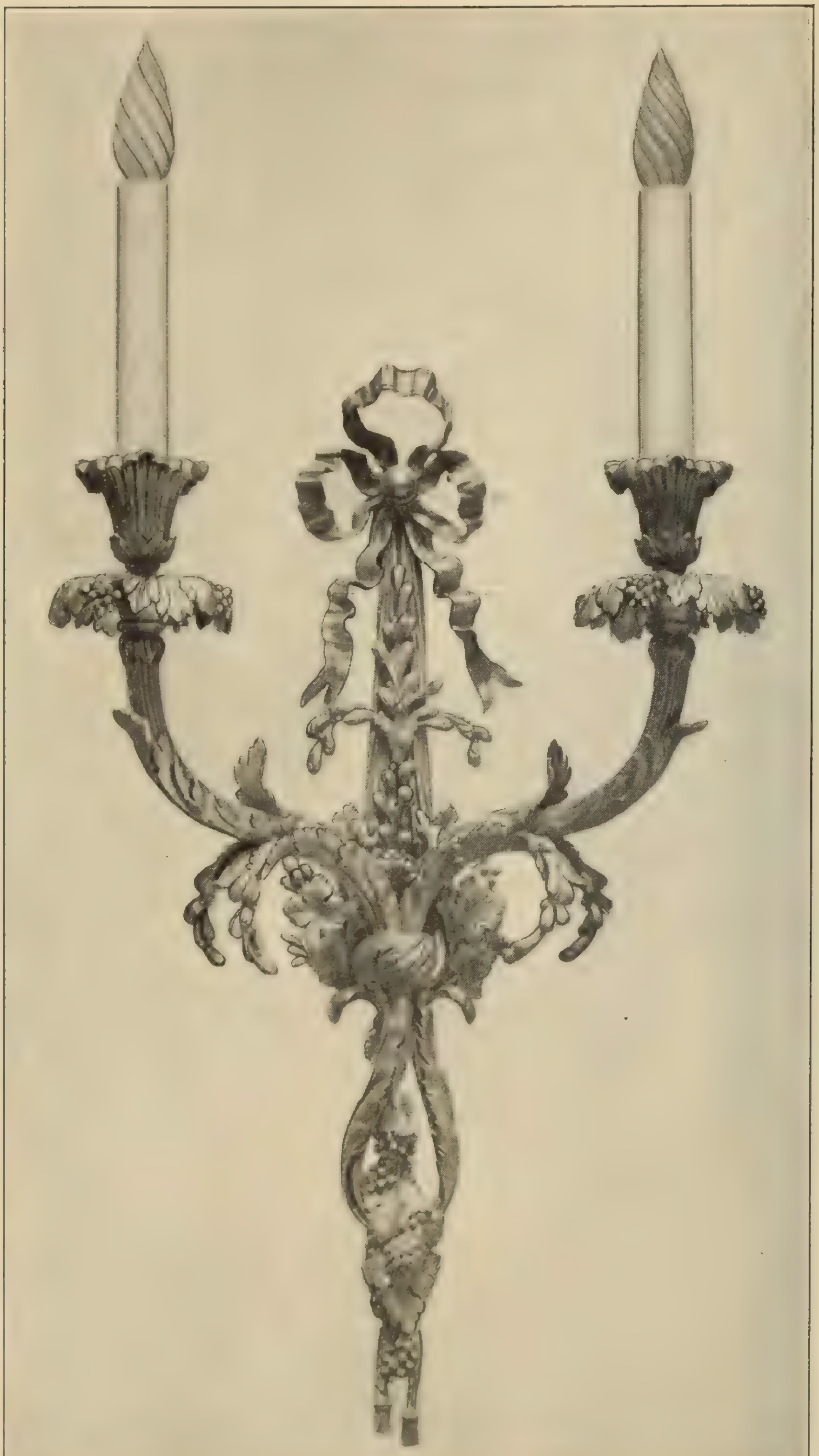


Fig. 10.

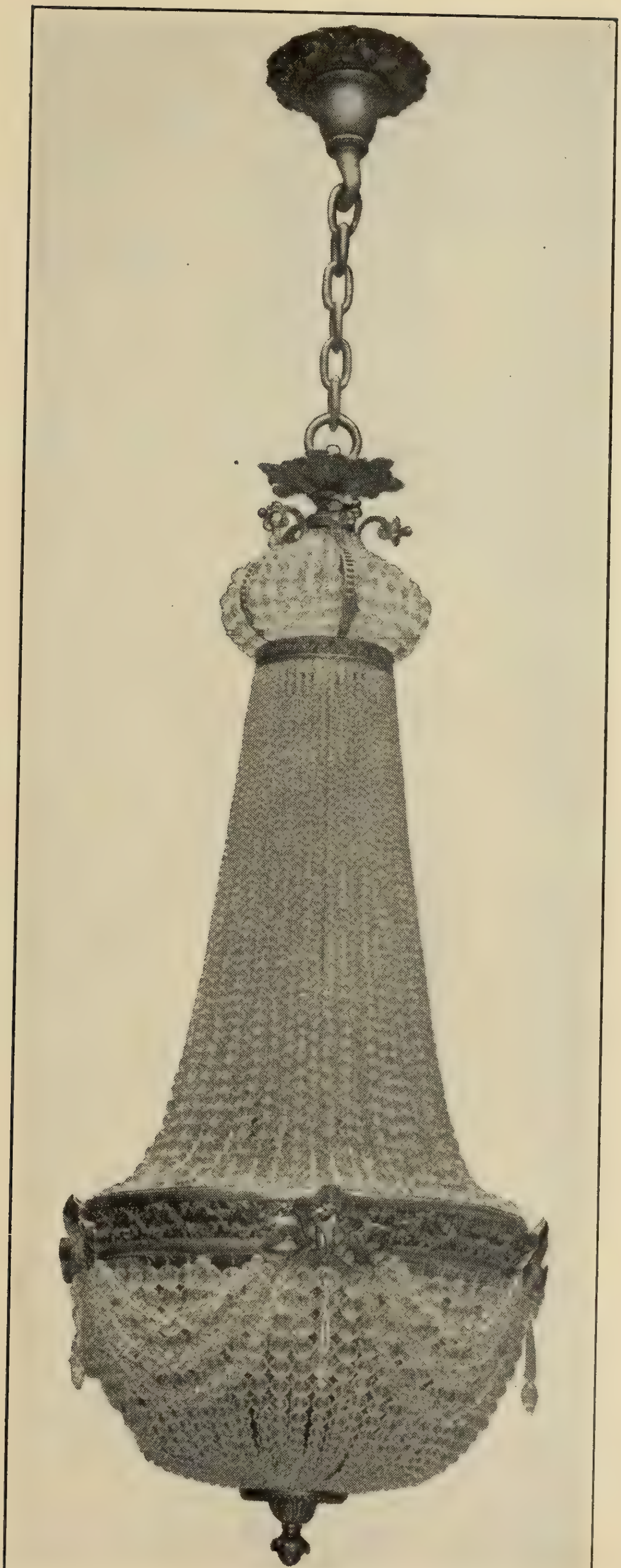


Fig. 11.

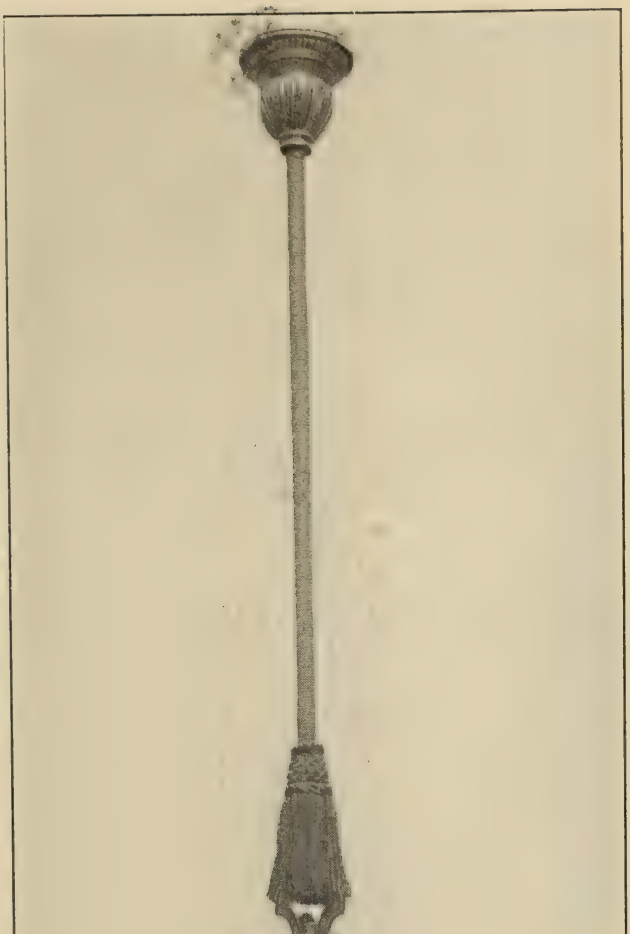


Fig. 12.

if for no other reason than that "necessity is the mother of invention," as it has always been. As it is proposed in this paper to gather together some of the records bearing upon the architecture of the centuries and the relation that the artificial illumination bears to the architecture and decoration of these periods, it is not well to pass on without giving a short survey of what building activity was exercised within the English province of America during the Colonial time.

The art of this period, including also the first twenty years of the 19th century is generally called Colonial. Some object to the term, saying that there is too much variety of style to come under one head and that, moreover, the best work was executed long after the original colonies had become provinces and even later, but the term has been in use so long and is so suggestive and comprehensive, that it would be difficult to find one more acceptable. Object as we may to the words Gothic and Colonial, we cannot spare them, for no other words call up to mind so complete a picture, not only of all the peculiar conditions, social, religious and political which produced the Mediaeval, ecclesiastical architecture of Europe and the 18th century domestic architecture of America. In this domestic architecture there was an evolution and a growth just as truly as in any other style. If the perfection of Greek art remained unaccountable until the archaeological discoveries on the banks of the Nile and the Euphrates, still less would one understand the Colonial art without knowledge of the preceding styles.

As we all know that America owes much to Europe and that the Colonists decorated their homes with many things brought from the mother-country, it would be well just here to direct our attention to the works of two architects, the brothers Robert and James Adam, who were responsible for the artistic value of many decorative objects of art in use then and to-day. These brothers who established a style known as "Adams" came of a family of architects; their united influence being felt right through the 18th century. They were not only architects, but designers of interiors and house furnishings, such as many pieces of furniture, platedware and other objects of art. Their inspiration was gained from the ancient work and as Robert Adam said:

We have introduced a great diversity of ceilings, friezes and decorative pillasters and have added grace and beauty to the whole by a mixture of grotesque stucco and painted ornaments, together with the flowing Rainceau with its fanciful figures and winding foliage. If we have any claim to approbation, we found it on this alone, that we

flatter ourselves we have been able to seize with some degree of success, the beautiful spirit of antiquity and to transfuse it with novelty and variety through all our numerous works.

It was their ability to seize and transfuse the beautiful spirit of antiquity into their work that brought into existence the many beautiful lighting effects designed and known until to-day under the names Adams. Among some of the most charming, we might mention the girandole of Lady Maria Ponsomby's Stratford place in London and the girandole in the Etruscan room at the Countess of Derbys. The beautiful pendant lamps with their oval and round glass shields, known in this period of work, were as famous as the candelabra, sconces and brackets designed, as they say, for "the wainscoting of a room." These splendid pieces have been an inspiration for many a designer even of to-day, who has made a study of their work. With the growth and popularity of the English home in America to-day and with the many architects and decorators who are designing along these lines, and in many cases expressing their own individuality in their work, it is incumbent upon the designer in connection with the illuminating engineer, to bring into existence new lighting pieces, just as graceful and original for modern use as those designed and made for the use of oil and candle—following as closely and departing from the precedent which controls only so far as the architect and decorator depart. The size of the electric bulb in connection with its large socket in popular use would, it seems, make the designing of graceful lighting effects almost impossible; but if we remember that the men who brought into existence new pieces for oil and candle had just as many obstacles to overcome and yet accomplished what they did, we will venture to say that if the designer of to-day would study their methods and also study the various styles in which he is working, he too could overcome the many disadvantages that the use of electricity imposes upon him. The universal use of the lamp in this country gives the designer a much larger field, and the fact that the introduction of the electric bulb in connection with the lamp and lantern does little to harm its artistic value, opens the door still wider for the introduction of lighting effects in which the illuminating engineer can play as prominent a part as the designer of the ornament.

As we said before that America owes much to the mother-country and Europe and as the many household utensils, furniture and lighting effects have been in a way borrowed from them, it is the duty of the illuminating engineer and designer of lighting effects to study their problems together in connection with the work of the architect and decorator and to produce

Fig. 13.

new lighting effects, departing from the controlling precedent of the period in which they are working only so far as the architect and decorator have departed in expressing their individuality in their work.

As we have spoken of the Adams period, Fig. 13 will convey some slight idea of the beauty of this ornament. The source of light, as in the French period, is the candle which has been in this case "modernized" to the use of electricity.

In Fig. 14 is shown another type of so-called Colonial fixture

Fig. 14.

in which the lamp motif is followed. Here again the electric lamp is used as the source of light, but the beauty of the original form of construction has been carefully preserved. In this case the intensity of the light may be sufficient to furnish adequate illumination, but should not be so bright as to destroy the charm of the design.

In Fig. 15 is shown a still different form of Colonial and one that has been "modernized" almost to the last degree. In this

fixture the beauty and simplicity of the ornament are preserved, but the form of the structure gives full recognition to the modern method of using the electric lamp. The illumination from such a fixture should be such as to satisfy the most ardent lover of efficiency.

It has been left for L'art Nouveau, which seems now to be gaining ground in Europe, to produce distinctly modern lighting

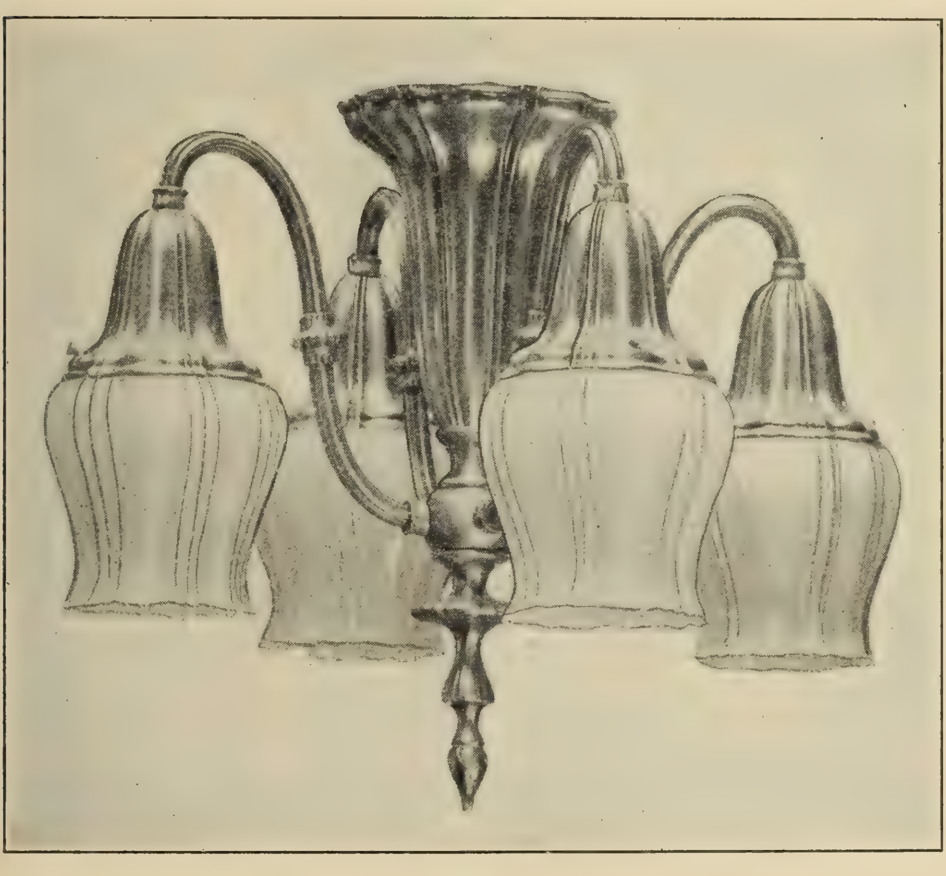


Fig. 15.

effects with all the true meaning that electric lighting implies. With the free treatment of the ornament the door is swung wide open at last for all the individuality of expression that the architect and the designer can summon to their aid. In this strictly modern style we are permitted to display the electric wire in connection with the socket and lamp and thus to stamp upon the lighting instrument the fact that it has been designed and made for the use of electricity, just as the designers in olden times,

with their various lamps and candelabra, expressed the fact that their fixtures were designed and made for the use of oil or

Fig. 16.

candle. It is in this field that the art of the illuminating engineer and designer of lighting effects combined may find its greatest opportunity for unrestrained expression.

Fig. 16 illustrates a type of L'art Nouveau fixture that is designed solely for the use of the electric lamp. In this case the lamps are pendant, and the resulting illumination should prove excellent.

In devoting so much space to a consideration of the history of illumination through the various recognized architectural periods we have felt that there is much to be learned that will be of value in guiding our work as illuminating engineers, and in at least broadening our view of the field of illumination as related to architectural structures. Even if the illuminating engineer is concerned only with the development of new electric lamps, with the designing of special reflectors, with the generation and sale of electric current, or with any of the various branches of our profession that direct his energies in one narrow specific direction, still he may be interested in the proper appliances to be used in the artificial illumination of the home or public building. On the other hand, if he is to be of material assistance to the architect in planning the lighting, to the fixture designer in designing the fixtures, or to the client who looks to him for advice in this direction, he must possess a knowledge of the proper relation of illumination and lighting fixture design to the various important periods of architecture.

We have attempted to show how the development of the various appliances for lighting, the lamp, the torch, the candle, the oil lamp of Colonial times, and finally the modern electric lamp has been followed by a development in artistic treatment of the appliances. In the hands of skillful designers these various illuminants have become so associated with the fixtures of these periods that we lose sight almost entirely of the appliance as such but see only the beautiful structures that furnish harmonious decoration as well as illumination. Illuminating engineering in its modern meaning they perhaps did not know; photometric curves and Rousseau diagrams were not then developed; but in the artistic handling of the appliances of their times and in the lighting of the interiors that have been preserved to us to-day they show the hand of the master in their art. In our account of the historical development of the art of illumination and the treatment to be given to various periods we stated

that governed by the architects individual treatment of the period of architecture from which he gathered his inspiration the illuminating engineer working with the fixture designer may produce lighting fixtures that will display the same skill in utilizing the latest modern appliances and thereby attaining the same economy in the construction of the fixture as has been shown in the use of modern construction of steel and iron in connection with a period of architecture that at its first development made use of entirely different means and materials for its structures. A few of our illustrations showed fixtures that combine or could readily combine a fair degree of efficiency with a treatment of design entirely in harmony with the locations for which designed. To go a trifle further, we show in the following illustrations a few fixtures that have been designed for peculiar conditions; but conditions which were exacting in their requirements that there should be perfect harmony between fixtures and architecture. Some of these cannot be classified with any of the periods of architecture that have been mentioned.

Fig. 17 illustrates a fixture designed for a large court room. In this case a certain amount of indirect illumination is obtained by reflection from the ceiling, while a soft light through the panels of glass bring out all the beauty of their coloring.

Fig. 18 illustrates a unique Chinese design in which excellent illumination is obtained on the table or space below the fixture.

Fig. 19 is a fixture that was designed for unusual conditions. The lighting of mural paintings on the upper walls was desired, accompanied by a treatment of the design and ornament of the fixture that should meet exacting architectural requirements. The light of the electric lamp is softened by the beautiful texture of the glass of which the flames are constructed.

Fig. 20 illustrates one of the earliest forms of oil lamps modernized for the use of electricity. The use of mica in this construction gives a soft and pleasing effect that greatly enhances the feeling of the design.

In Fig. 21 is shown how the humble gas light may be clothed in beautiful form. In this fixture a cluster of small mantle lights throws the light down through a cut-glass dish and give a soft pleasant light to the dining table beneath the fixture.

As we admire the work of the fixture designers of the past, we admire most of all their ability to make use of the illuminant

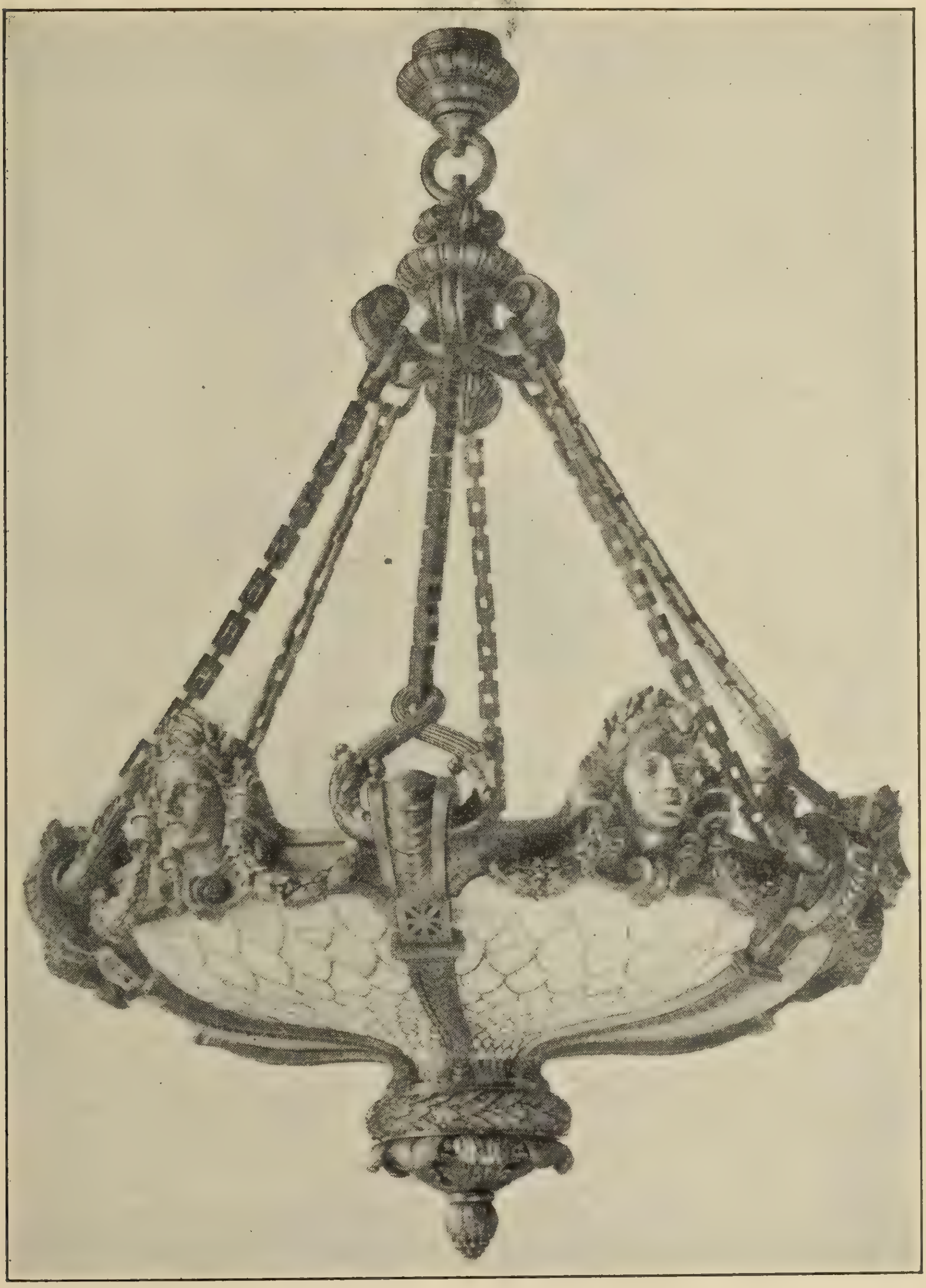


Fig. 17.

that was at their disposal. Where is such beautiful handling of the lamp and torch as in the Greek and Italian? Where can we find such exquisite designs for the candle as in the French

Fig. 18.

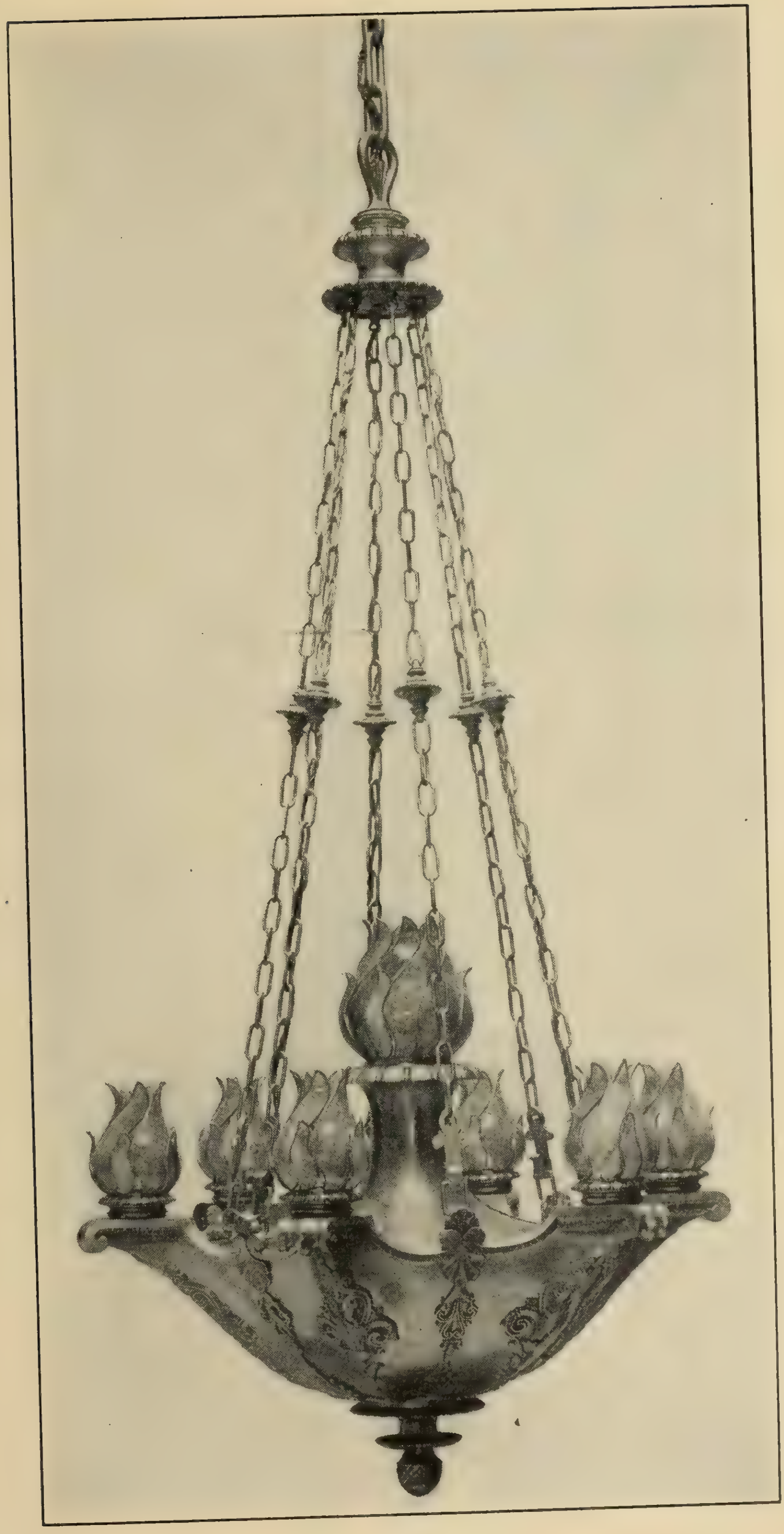


Fig. 19.

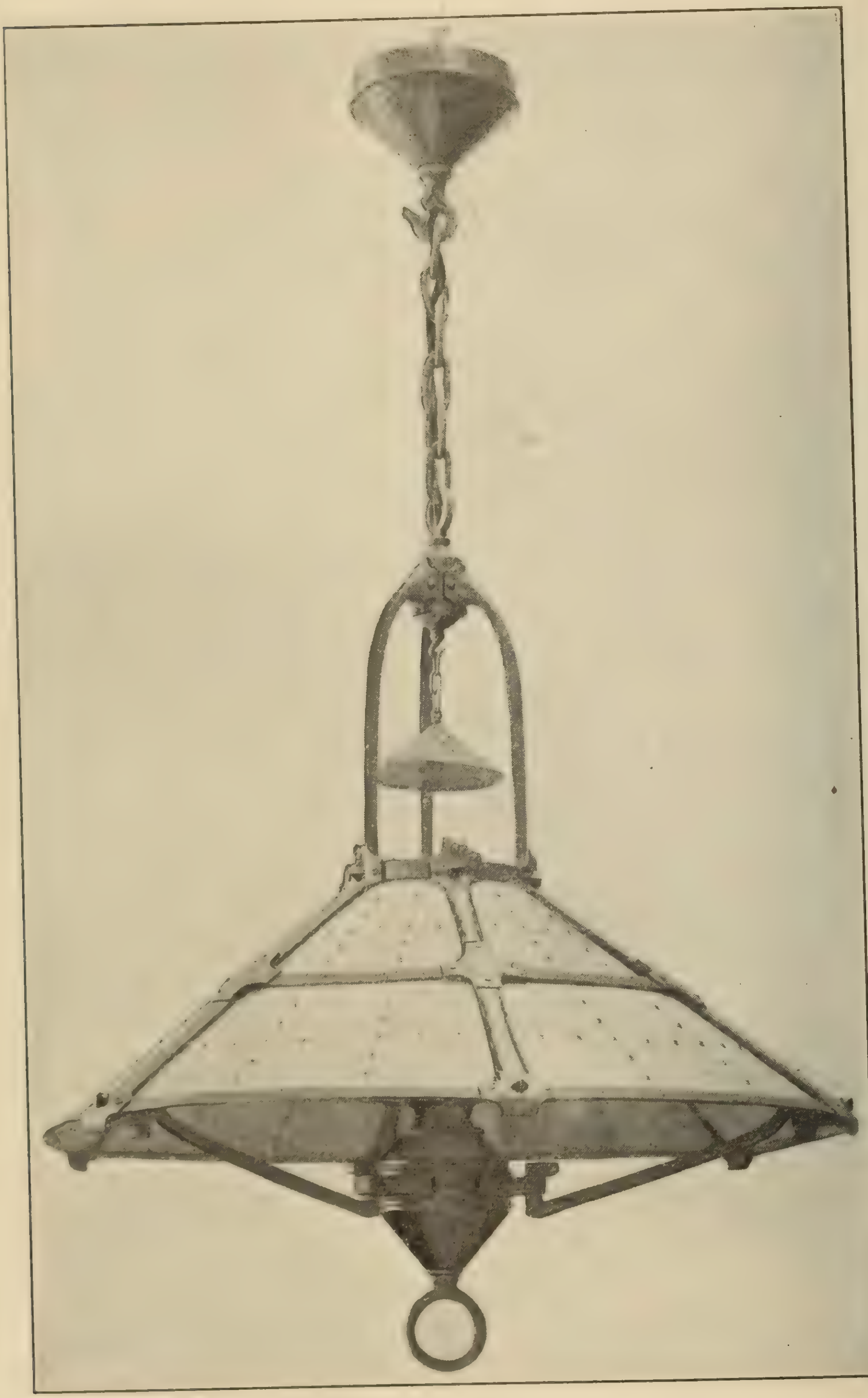


Fig. 20.

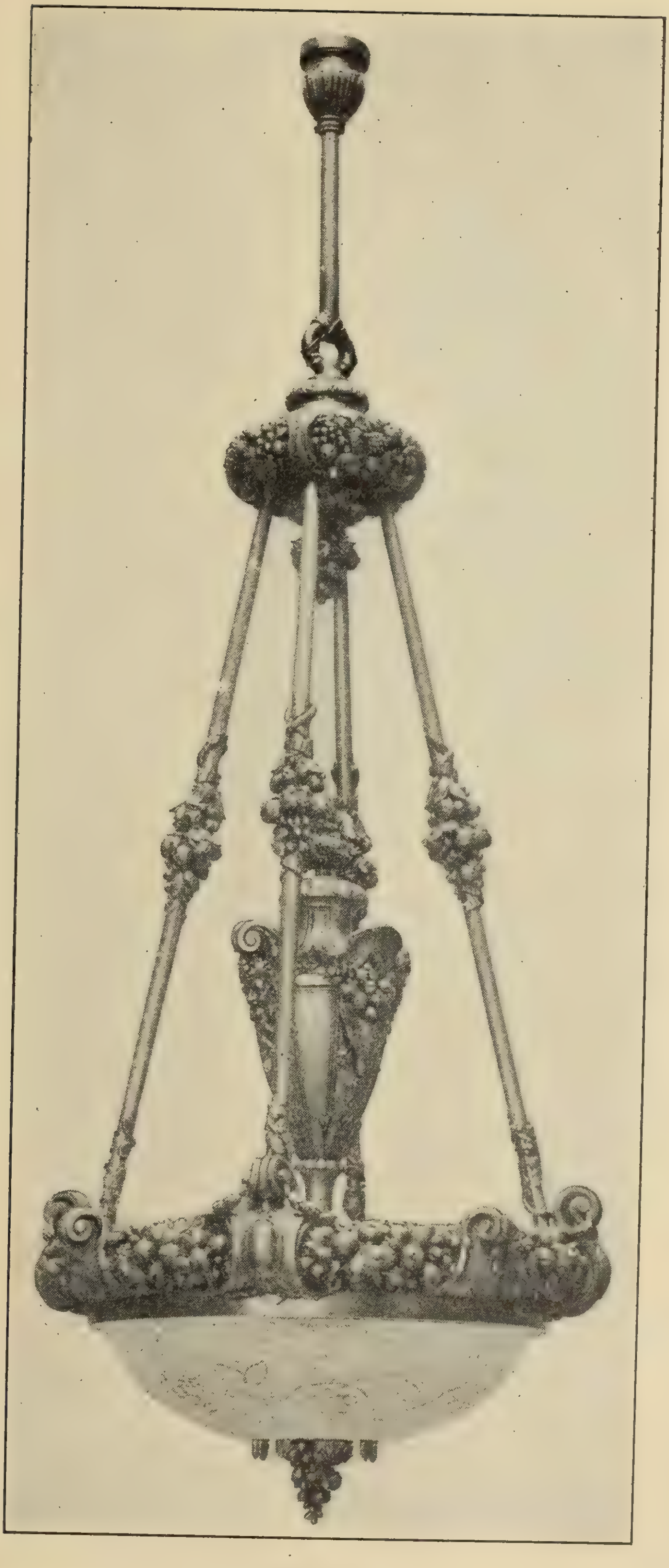


Fig. 21.

and the Adams? And where such artistic ability to use an apparently clumsy appliance, the oil lamp as in the Dutch and Colonial? Shall we not continue and say where is the electric lamp with its high intrinsic brilliancy and its powerful units to be given better treatment than in the lighting appliances to be developed in the 20th century?

The field is a wide one. Is the illuminating engineer to sit back and say he cares nothing for aesthetics? That he cares nothing for the design of the lighting appliance nor its fitness for its architectural surroundings, that he will withhold his stamp of approval from anything that is not thoroughly practical, economical and efficient? We firmly believe that the illuminating engineer who decides that his province is entirely outside of anything aesthetic will be necessarily eliminated in the consideration of problems relating to the proper lighting of buildings having any well defined period of architecture. As we view the situation to-day we cannot see how it can be otherwise.

And now what of the thousands of modern structures that are being erected in all parts of the country that embody in their interior construction no defined period of architecture? The modern middle class home, the office building with its box like offices, the library planned without interior ornamental treatment, the store, the lecture hall, or church or class room, strictly modern in construction and equipment, all of these can be lighted in the most modern way and with most modern appliances. This has always been the case. Go through any of these modern structures and find if you can anything enduring in their lighting equipment. The fixture of ten years ago or even five years ago may be considered obsolete by progressive illuminating engineers. Our profession is making such rapid strides in the direction of developing efficient lighting appliances that this must necessarily be so. What shall we use in these cases? We must use only efficient apparatus for our lighting as for our heating, ventilating and other mechanical functions. Ornamental design should be called in to give the appliance selected some semblance of beauty of line or ornament, some external appearance that will not seriously offend an inborn sense of the harmonious and the beau-

tiful, some treatment that will convert the strictly mechanical into a structure that will not offend the eye.

In looking over the work of some of the members of our profession (and we are most interested students of all that is being done in this direction) we are glad to see that there is still a strong feeling that everything must not be sacrificed to efficiency and economy. We see designs suggested by the illuminating engineer working on the layout of the buildings that are good and that are appropriate, designs that may properly carry also the stamp of approval of the architect and the fixture designer. To what extent these designs are inspired by the architect under whom you are working we cannot tell, but in any event the results are satisfactory. On the other hand, we are sorry to say, we see designs that are not apropriate, we see designs that show efficient appliances but that are spoiled by meaningless ornamentation. Through our hands pass designs that could be changed into things of harmony and even beauty without at all sacrificing any of the desired value as efficient apparatus. For the sake of attaining efficiency, many of these designs are mechanical monstrosities, they violate every rule of proper form and proportion. As one of our writers has said "there is no more excuse of making a barbaric, soul-shocking hole out of a workshop than is the case with a theatre foyer," not alone out of a workshop but out of an office, a classroom, a store, a living-room or any other location where the lighting fixture is before our eyes during the daylight hours as well as during the few hours that it is in use as a source of artificial illumination. We need not search our souls for our profoundest sense of the aesthetic to condemn the use of such structures: our common sense will do it and do it most effectually.

The so-called scientific fixture about which we are hearing so much in these days shows to a marked degree the efforts that are being made to meet the requirements of efficient and economical illumination. These fixtures represent the latest ideas of the illuminating engineer and as we have said before they belong to that class in which the fixture designer has yielded almost absolutely to the demands of the illuminating engineer. The large sale and extensive use of this class of fixtures show that they are filling

certain requirements for commercial use and are meeting with general favor. The use of the tungsten lamp in a pendant position together with a well designed and efficient reflector are the basis of the "scientific" construction but they form a combination by which the lamp interests the reflector manufacturers and the fixture makers can bring into concrete form a satisfactory structure for general use. Placed in the hands of the dealer or the central station salesman, together with clear and concise rules

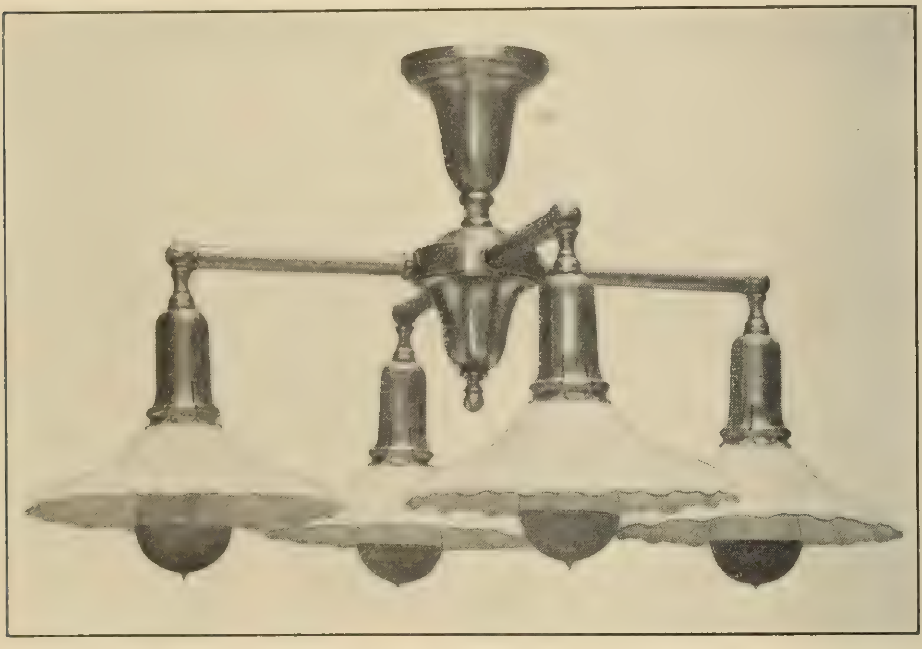


Fig. 22.

regarding the size of lamps and reflectors, the spacing of outlets, and other data, they are accomplishing a world of good for the betterment of our purely commercial lighting.

Figs. 22 and 23 illustrate types of fixtures that belong to this class.

As these fixtures are evident instruments of efficient illumination and are to be used under varying conditions, it is better to design them of a simple form and solid construction without profuse and meaningless ornamentation. The Flemish and square designs are better for this purpose although where done with discretion they may be ornamented to a limited extent to harmonize with the architecture of the surroundings.

Fig. 24 shows a fixture of this character having a design that is slightly above the ordinary commercial but which embodies all the features of the "scientific" construction.

For many uses the single light pendant such as Fig. 25 is coming

Fig. 23.

into more extended use and for certain conditions requiring nearly uniform illumination is very satisfactory.

It may not be amiss in connection with these pendants to decry the use of powerful lamps and huge reflectors. In our opinion the 100 watt tungsten lamp is amply large enough for nearly

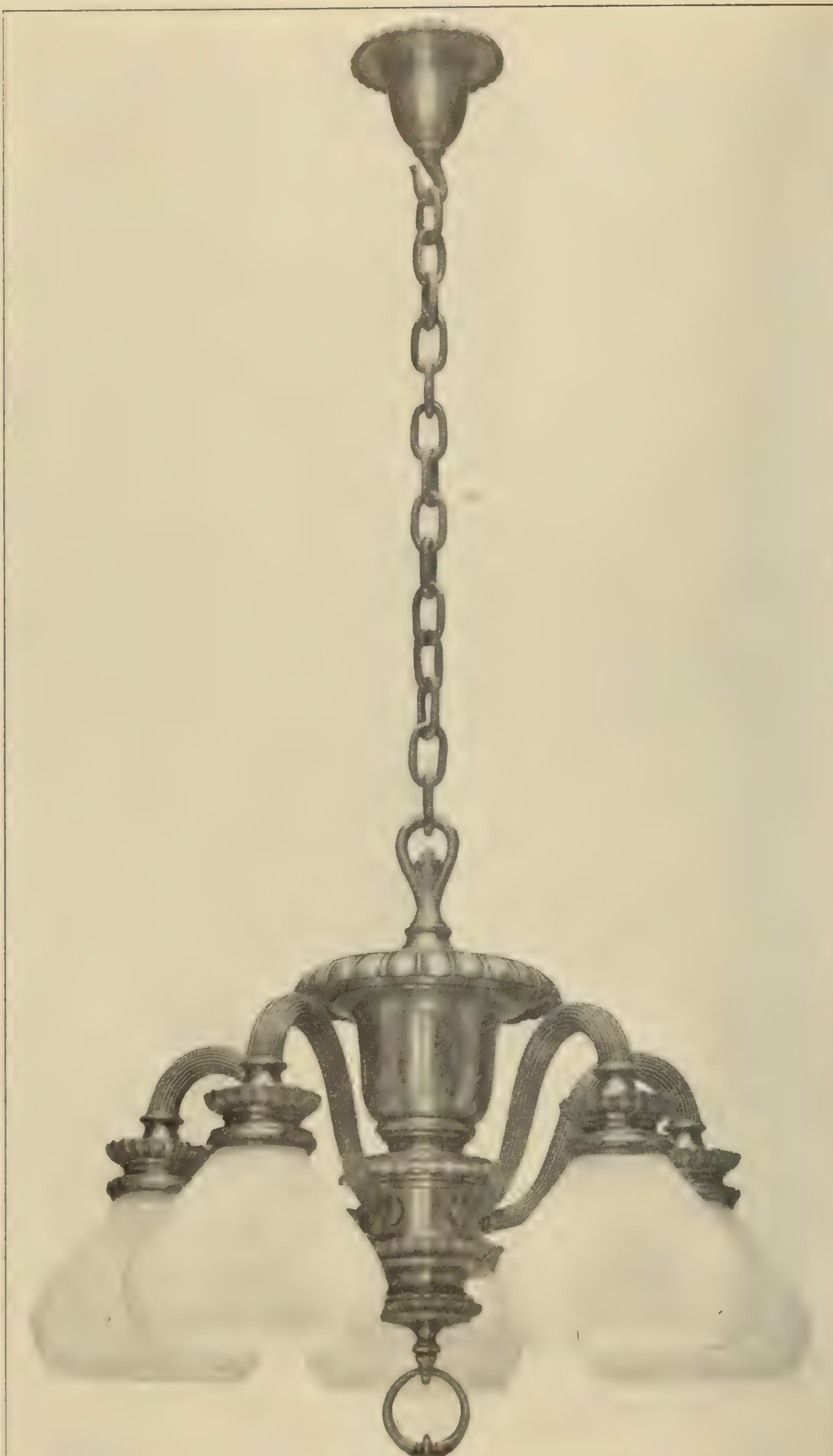


Fig 24.

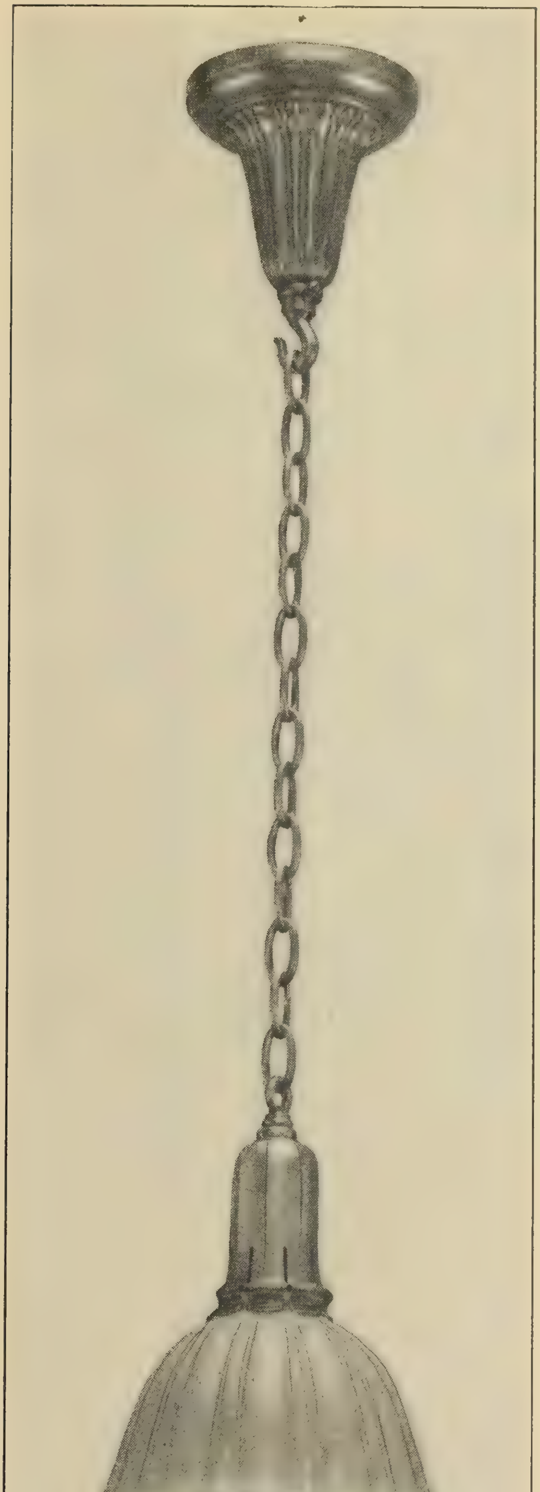


Fig. 25.

all cases, and permits of a design that does not appear clumsy or overpowering.

In speaking of the latest developments of fixtures for efficient illumination we might call attention to many peculiar and novel constructions. We might show fixtures designed solely for indirect illumination, we might show standards for libraries and reading tables, we might show fixtures designed for symbolic or spectacular effects, we might show fixtures in which the humble gas light has been wrought into pleasing and artistic form, and we might show even arc lights clothed in a covering that totally changes the ugly and ill proportioned commercial casing into a structure of beauty and harmony. All of these are the solutions of every day problems in which we have attempted to "combine science and art."

Probably could we read a detailed history of the progress of illumination we would find that in every age men have gone far afield in their attempts to create peculiar and extreme instruments of illumination, and although the path of time is strewn with discarded apparatus of this character, their work has not been all in vain. Behind them have come the more enduring forms; structures that have avoided the mistakes and eccentricities of these predecessors, but which embody that which is good, which make use of the same appliances but in a form that is pleasing, harmonious and artistic. Such we believe is the case to-day and in this belief we find the courage to refrain often from yielding to the demands of the minute. Where we disagree with progressive illuminating engineers it is generally for this reason—that we wish our work to endure longer than the fad of to-day which will be forgotten tomorrow.

We have enjoyed the task of preparing this paper and, our sincere regret is that it is so inadequate in the handling of this most important subject. We may have advanced no new ideas, we may have said things with which all cannot agree but we earnestly hope that we have at least given something that will help advance the cause of illuminating engineering in its broadest possibilities.

DISCUSSION.

A. J. Marshall:—The paragraph reading:

Is the illuminating engineer to sit back and say he cares nothing for æsthetics?—That he cares nothing for the design of lighting appliance nor its fitness for its purpose? We firmly believe that the illuminating engineer who decides that his province is entirely outside of anything æsthetic will be necessarily eliminated in the consideration of problems relating to the proper lighting of buildings having any well defined period of architecture. As we view the situation to-day we cannot see how it can be otherwise.

expresses exactly my views of this aspect of the subject.

I will even go a step further and say that the illuminating engineer who is so imbued with a love for utilitarianism and a corresponding lack of regard for physiological, æsthetic, and psychological considerations even in commercial installations, will create a state of things bearing on monotony. He will destroy individualism and find his work limited to extremely small fields.

When we speak of æsthetics we do not always necessarily have in mind much embellishment, the desire to sacrifice efficiency and economy. A lighting fixture must harmonize with its surroundings. On several occasions I have expressed myself that the correct manner of approaching a lighting installation is to predetermine the effect that it is desired to create.

F. J. McGuire:—New York has had many and great difficulties placed in its path in obtaining efficient and economical illumination through the medium of proper lighting fixtures. The difficulties arose in this way: the provisions of the charter of this city require that plans and specifications dealing with the proposed installation of lights in public buildings be submitted to and approved by a certain department. Accordingly, when architects employed for the purpose of formulating plans for public buildings would submit those plans to the supervising department, there was apparent a lack of knowledge of the primary laws of artificial illumination. This supervising department then endeavored to convince such architects that it was possible to combine the æsthetic with efficient in lighting.

I agree with Mr. Hopton that the man who proclaims himself an illuminating engineer and works along lines exclusively of efficiency and economy and sacrifices all æsthetic and artistic prin-

ciples is not and never will be, while he pursues such a course, a real illuminating engineer.

Bassett Jones, Jr.:—I am sorry that Mr. McGuire had so much trouble with architects, for I have not. Perhaps I have come in contact with a different class. The architect is I believe wide awake on the subject of lighting and realizes that the illuminating engineering can help him in many ways.

In fact there are several architects in the city of New York who in the last few years have become positively over enthusiastic on the question of illumination. There are a number of monumental buildings in course of construction to-day which have been practically designed around the lighting scheme. I have one particular public building in mind in which the architect laid down as one of the fundamental requirements that the second night the building was lighted, it should be necessary to call out the police reserves to handle the crowd. This, however, is carrying things too far. There is, I think a decided change of view both on the part of the architects and the illuminating engineers. Both are beginning to realize that the other knows something, and in my belief this is a very critical period.

A paper by Mr. Clifford was presented at the last meeting of this Section. His paper is like the proverbial writing on the wall. It is an indication of the turn of the tide in our direction.

A. J. Marshall:—I cannot refrain from paying my profound respect to the architect. I have found him the most satisfactory and pleasing gentleman to do business with, provided he is approached in a proper manner. They don't know it all, and their knowledge, especially of economies and efficiencies in the use of artificial light is quite meagre as a rule, but they are willing to learn, and their gratefulness is usually manifest.

W. H. Spencer:—The indirect lighting system is now recognized as a beautiful way to solve many propositions in illumination.

Bassett Jones, Jr.:—Mr. Spencer has mentioned that indirect illumination is very popular. I think it is a misfortune that it is popular. In another place I published an article on this subject, and there I tried to point out there that indirect light-

ing contained more pitfalls to trap the unwary than any form of illumination that had been devised. I think there are very few situations where it can be properly used. In many cases its use is dangerous, particularly in rooms likely to be occupied for any length of time. The system I have outlined produces absolutely direct illumination. There is no loss of perspective or loss of character in the room produced by it.

F. J. McGuire:—I have heard it stated that a form of lighting entitled by one engineer "direct-indirect illumination" creates a sort of semi-ghastly effect on the faces of the occupants of the room. Is this really so? I have heard that this form of lighting proves injurious to the eyes of those finding it necessary to remain a long time in a room where such lighting is in operation. I remember that when first entering the auditorium of the Edison building on West 27th Street, I experienced rather a pleasing feeling on my eyes. There seemed to be an absence of the ordinary lights and shadows that the eyes have become accustomed to have so many years. But after I had been seated for a while I experienced a more or less strained feeling on my eyes, similar to that produced when walking through the street on a bright, sunny winter's day after a heavy fall of snow. This feeling I understand is akin to that experienced in snow blindness. I found later that several others were affected in the same manner. Is this form of lighting the sole cause of this strained feeling on the eyes?

Bassett Jones, Jr.:—I remember the auditorium Mr. McGuire mentions and I remember very well my own suffering resulting from sitting in it for an evening.

It is downward direct light flux which is essential and the use of indirect lighting with its consequent indeterminate flux gives the eye no chance to protect itself. Such lighting subjects the eye to conditions which it cannot meet and control.

A. A. Wohlauer:—In the various "periods" mentioned by Mr. Hopton there was usually one particular kind or type of an illuminant which the fixture designer had to deal with. So we find the candle preeminent in the Renaissance just as we have the incandescent and arc lamps at present. While to-day we can arrange the lamps in whatever position we find preferable,

in former times the people were obliged to have the lamps pointing upwards to the ceiling. However, if we want to utilize a fixture design of that age we have means to do that to the best advantage, for instance by applying the so-called indirect illumination; in fact it is rather easy to conform the artistic ideas of a certain period with economical and efficient effects, as is shown by the numerous examples presented in the paper.

MEETING AT CHICAGO, APRIL 14, 1910.

The Chicago Section of the Illuminating Engineering Society met in the rooms of the Western Society of Engineers at 8:00 p. m., Thursday, April 14, 1910.

Chairman Scheible:—As a little departure from our usual program, we are to take up tonight a definite problem in lighting. The plan is of a store 30 ft. wide, 100 ft. long and 16 ft. high, with a light cream colored ceiling, and shelving up to within a few feet of the ceiling, so the walls cannot be counted on for reflection. A number of plans will be presented so that we may get an idea of the different ways in which the problem can be solved.

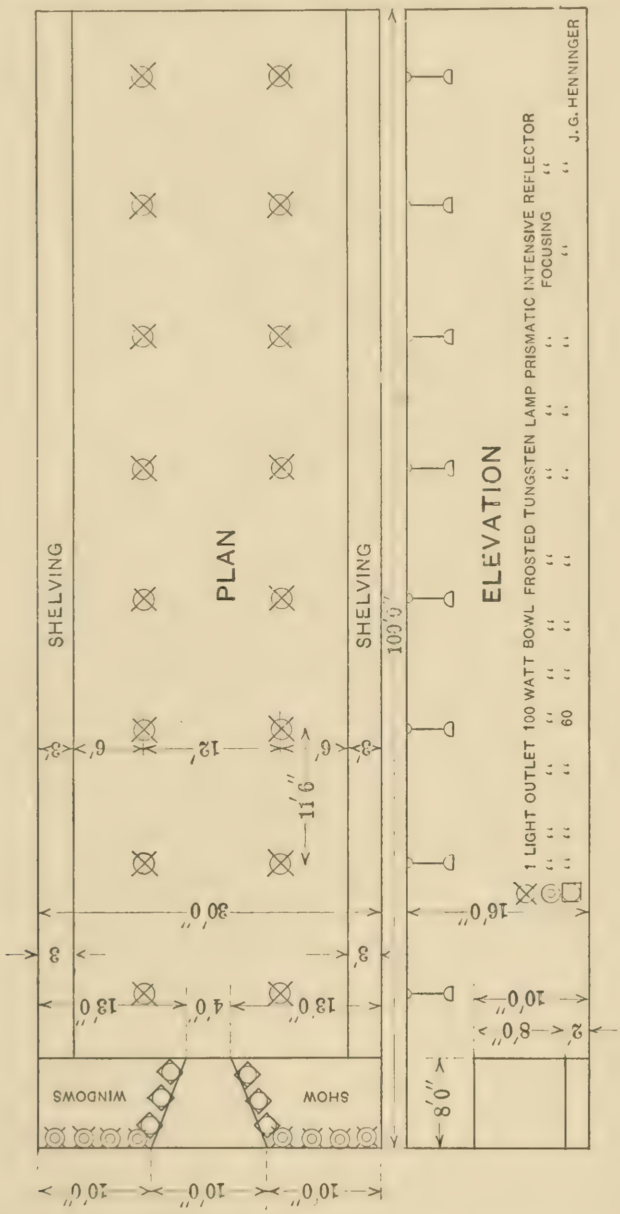
J. G. Henninger:—I will take up the store-room first, with the idea of obtaining an average intensity of illumination of 3 foot-candles, on the counter level, as specified in the problem. The shelving runs up to within 3 feet of the ceiling, so that the area occupied by it would not be included in the area used in computing the wattage of the lighting equipment. In my layout I have used 16 outlets, arranged in two rows of 8 each. The outlets in each row are 11 ft. 6 in. apart, while the rows themselves are 6 ft. out from the wall cases. Each outlet should be equipped with 1 100-watt bowl frosted tungsten lamp fitted with a prismatic reflector. The units should be hung 12 ft. above the floor. This equipment will produce on the counter tops an average intensity of illumination slightly in excess of 3 foot-candles. This value can be approached more closely by varying the height of the units above the plane of illumination.

The advantages of this system are manifold. With the light coming directly down upon the counters, a customer will not have to turn round in order to inspect a piece of merchandise. Furthermore, this scheme will provide light behind the counters where the clerks can use it to advantage.

Omitting the area occupied by the case, the effective area of the store is 92 ft. by 24 ft. or 2,208 sq. ft. The power consumption with this system will be 1,600 watts or 0.82 watts per sq. ft.

A system of this kind, as recommended for the store, is very flexible. The units can be connected either singly or in groups, thereby giving the greatest flexibility and highest operating

economy of system. Toward dusk a man might wish to light every alternate row, for instance; then as it grew darker he would light the remaining units. The light is of excellent quali-



ty and will be well diffused. The lamps operate at an average efficiency of 1.2 watts per candle.

Now as to the windows: I do not think anyone has a right to take a plan of a window and say positively that any given system is best for that window unless he makes certain assumptions, *i.e.*, as to the kind of goods displayed, the results de-

sired by the merchant, etc. Each proposition should have its own treatment.

In this case I have assumed that the merchant wishes to have a transparent sign along the top of his windows. I have suggested four 100-watt bowl frosted tungsten lamps with focusing reflectors and three 60-watt bowl frosted tungsten lamps, also with focusing reflectors for each window. Every alternate unit should be tipped at an angle of between 10 and 15 degrees; the other units should be tipped still further at about 30 to 40 degrees from the glass. The intensity of illumination in the plane of dress of the window, with this installation, will be about 16 foot-candles. The power consumption for the windows will be about 5 watts per square foot. In some of the larger stores the wattage per square foot frequently runs higher than this, often to 10 or 12. This tipping of the reflectors at different angles will thoroughly cover the angle of dress area of a window.

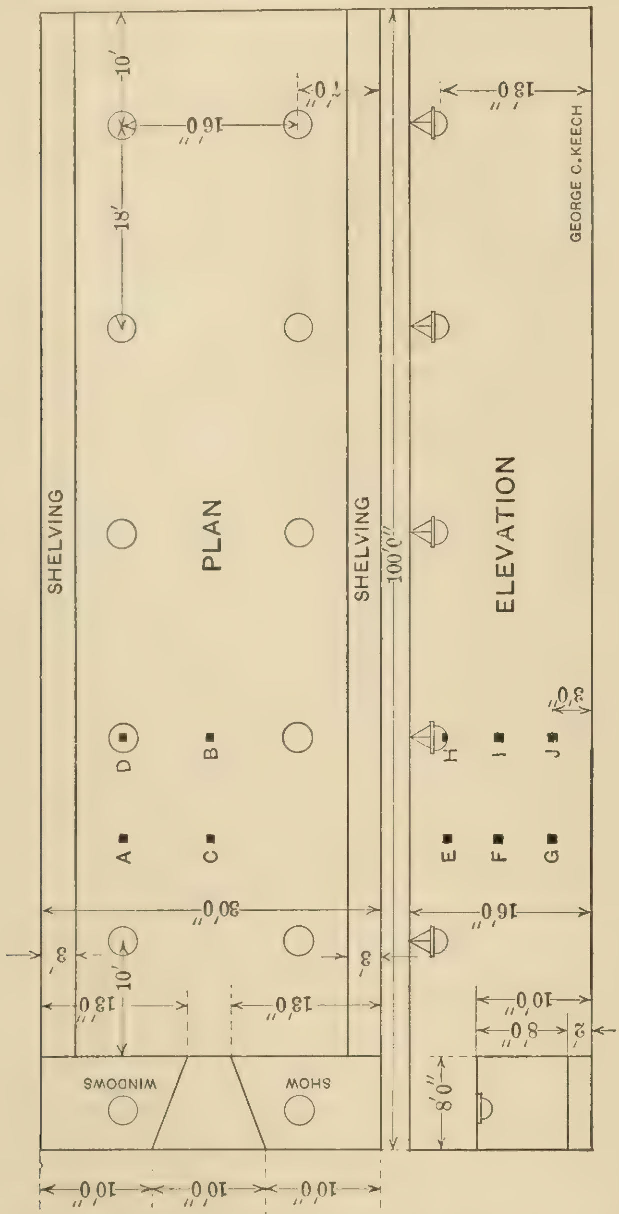
Geo. C. Keech:—The height of the lamp from the floor is 12 ft. and the counter is assumed to be about 2½ ft. high. The 100-watt lamp directly above a certain point on the counter will give 80 mean horizontal candle-power. If your units should give about 80 candle-power hemispherical, what will the reflector add to that?

J. G. Henninger:—The mean spherical candle-power of the 100-watt lamp is about 62, while that of the combined lamp and reflector is about 55. The downward candle-power from this combination is approximately 120. The intensity of illumination produced beneath each unit independently of the other units will be about 1.29 foot-candles.

Geo. C. Keech:—The unit consists of a mercury vapor tube, consuming 125 watts, bent in a circle, and in the center of that circle is hung a 100-watt tungsten lamp, all enclosed in a hemispherical globe, either frosted or prismatic. The peculiar color from the Cooper-Hewitt tube is overcome by the red rays of the tungsten lamp and the diffusion of the two through the globe is such that the color approximates daylight as nearly as that of any other artificial illuminant. Above this tube which is in a horizontal plane is a concentric reflector, which, allowing for the absorption of the globe, gives the unit a mean hemispherical candle-power of about 300. The curve of illumination is like a

flattened so that the maximum intensity ranges from vertical to nearly 45 degrees.

I have laid out on this plan, 10 units. The first lamps are



10 feet from the end, the next lamps 18 feet back, etc. They are 16 feet apart across the store and 7 feet from the edge. These lamps are hung 13 feet above the floor or 10 feet above the counter level. Each unit alone will deliver 3 foot-candles on the counter and with the aid of the illuminants nearest to it the aver-

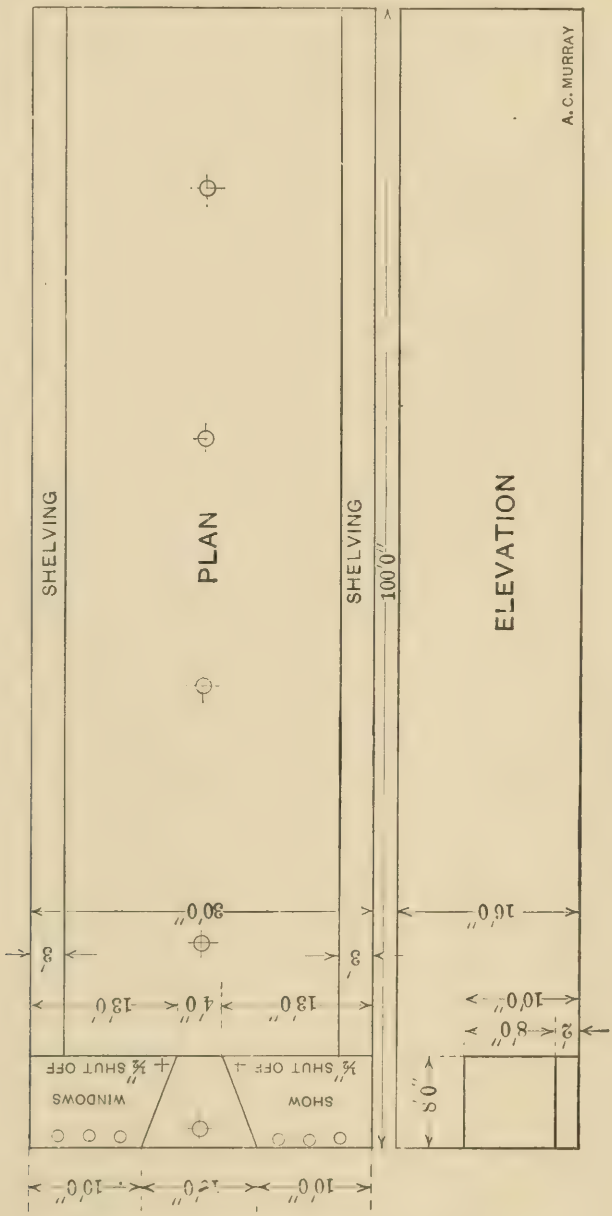
age foot-candles on the counter will be between 3.26 and 3.15. It happens that with this arrangement the distribution is very even. Take a point directly in the middle of a square bounded on the corners by four units. At this point the illumination is 3.19 foot-candles. Between any two outside lamps the illumination is 2.98 foot-candles. The illumination at the top of the shelves varies from eight foot-candles to four foot-candles. That is more than is necessary, but it cannot be helped. I have allowed this, however, and if there were goods to display here—the higher the illumination the better—the goods could not be observed by the customer at a distance. The illumination on the shelving at the counter level will be about 2.5 foot-candles and at a point midway between top and bottom it would run about 4.5 foot-candles. My idea was to have the illumination all over the counters as evenly as possible and I aranged the units primarily to meet that condition.

As far as the window lighting is concerned this is somewhat of an assumption. A unit of this size placed near the corner will deliver about 6 or 8 foot-candles throughout this space. The total wattage in the store is 2,250 or 0.8 watts per square foot. I am certain that these units will give that illumination (3 foot-candles) at the counter level all the time as I have figured 3.15 to 3.26 foot-candles to allow for any dust that might collect on the globes. There is practically no deterioration in the light from the mercury vapor tube and there would be little more in the tungsten lamp. I do not believe that I have figured the size of these units too large to give the proper foot-candle illumination. I disagree somewhat with Mr. Henninger as he is using a 100-watt unit giving 80 candle-power which with a reflector may deliver as high as 170 candle-power, while I am using one giving nearly 330 candle-power. He has 16 units as against my 10.

Each unit consumes 225 watts, 10 units being 2,250 watts, or 100 watts each for the tungstens and 125 watts for the tubes. I used 2,900 sq. ft. for the floor area.

A. C. Murray:—The store proper is to be lighted with four 4-light reflexoliers, each to be trimmed with prismatic reflectors suspended 10 ft. from the floor, the inner cylinder to be clear glass.

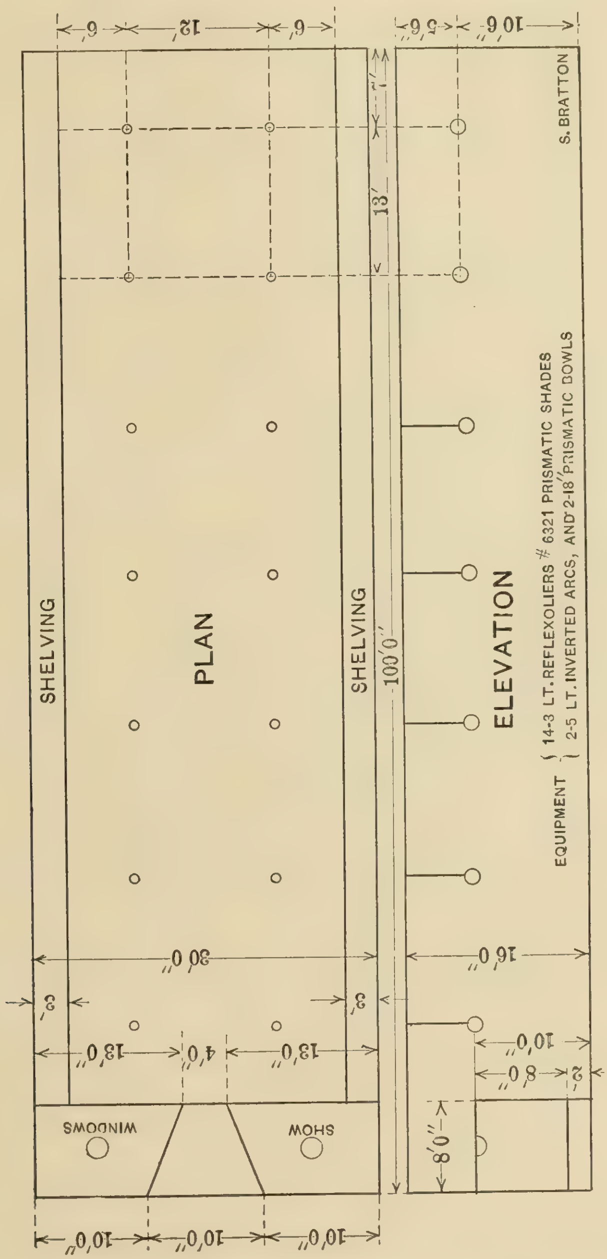
The windows to be lighted with three *reflex* lamps in the front of the window and to be trimmed with an angle shade, the lamps to be used on an ordinary square loop bracket in



verted to do away with the goose neck. I would suggest that the pipes in the basement be run from one feed on which at a convenient point a shut-off be placed, this to be attached to an ordinary alarm clock which may be set to put out the lights

in the window only there by putting the lights out at any hour that may be desired. The front of the store to be lighted with one 4-mantle inverted portico lamp.

J. C. Bratton:—They say a change helps, so we will see what this will do for us. In figuring my plan I left out the shelving,



which gives me 2,208 square feet for the working plans. I propose to use 14 3-light reflexoliers with prismatic shades to be placed in two rows 7 ft. from the end of the building, and

spaced 13 ft. apart, making a total of seven 3-light reflexoliers on each side, and have placed them 6 ft. from the shelving, thereby making it 12 ft. between the lamps across the room. The bottom of the mantle is 8 ft. above the lighting plane or 10 ft. 6 in. above the floor. Immediately underneath the lamp I get 6.89 foot-candles, 2 ft. from the center I get 6.13 foot-candles, and 6 ft. 6 in. from the center, I get 3.86 foot-candles 2 ft. above the working plane. Four feet above the working plane, and 6 ft. 6 in. from the center I get 3.17 foot-candles, and 6 ft. 6 in. from the center, 6 ft. above the working plane I get 0.824 foot-candles. If you figure on lighting the top of the shelves, my foot-candles drop pretty low, something like 0.214. I could have gotten along very well by leaving out a couple of lights, but had to make it two over in order to have it uniform.

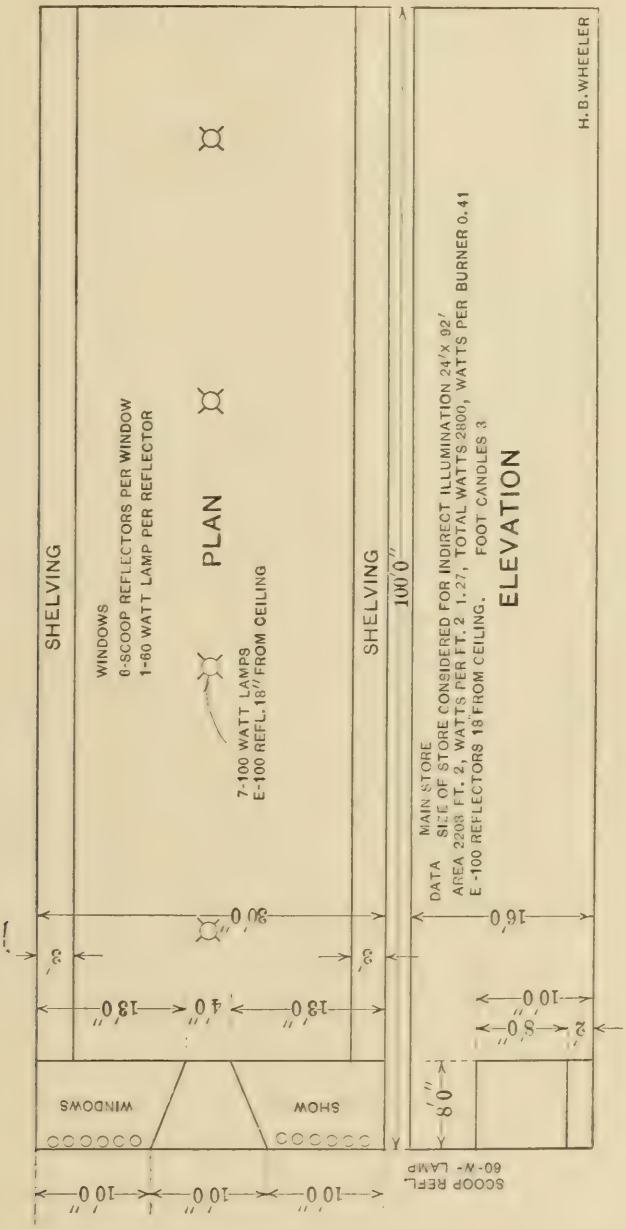
When I came to the windows I took it for granted they were not ventilated, and I had to figure out something so as not to get the windows too warm inside, so I used two 5-mantle inverted arc lamps set in 18-in. prismatic bowls in the center of the top of the windows. In the center of the window, immediately under the bowl, I got 6 foot-candles; moving over 2½ ft. from center of the window or fifteen degrees I got 6.5 foot-candles. At 30 degrees or an extreme corner of the window I got 4.7 foot-candles. At 30 degrees or an extreme corner of the window I got 4.7 foot-candles. At 40 degrees, or 4 ft. from the bottom of the window I got 13 foot-candles. On an average I get more illumination than you called for on your working plane, something better than 3.5 foot-candles.

The inverted Welsbach reflex mantle rated at 80 candle-power is used. The window light has the same sized mantle. The total consumption for the entire outfit, windows and interior lighting, is about 179 cu. ft. of gas per hour.

I tried the two-light scheme, but I could not get the spacing just as I wanted it. I think it would have been well to raise the lamps a little instead of having them 8 ft. above the lighting plane, probably about 11.5 ft., then I would have gotten an average of 3.12.

H. B. Wheeler:—For the main part of the store I have considered the area to be illuminated 24 ft. by 92 ft., making

a total of 2,208 sq. ft. I have divided this area into bays 23 ft by 24 ft., and have placed an outlet in the center of each bay. I have used seven 100-watt clear bulb tungsten lamps in each fixture. The fixtures are to be suitable to hold the lamps in the



right relation to the reflectors, and the top of the reflectors the proper distance from the ceiling. The tops of all reflectors are to be 18 in. from the ceiling. Using 100-watt lamps, seven to a fixture, makes the total wattage of the store 2,800, and with

an area of 2,208 sq. ft., gives 1.27 watts per square foot. Using 0.41 watts per lumen gives a trifle over 3 foot-candles as the average illumination throughout the store.

Although the wattage may be somewhat higher than various other methods presented, I feel that the results in illumination will justify the expenditure in wattage. The up-to-date merchant of to-day is looking for results, and he realizes that an attractive, bright, evenly illuminated store is a necessity to obtain business. The eye comfort system of indirect illumination has fulfilled these conditions, and made better store lighting possible. Under indirect light the finer points of the various goods and articles on display are brought out in detail and no disagreeable shadows or glare are apparent. Better results should be obtained by indirect illumination, because the seeing qualities of the eye are increased to a greater extent by the indirect system than with the direct. The reason for this is that the seeing qualities of the eye are better under the eye comfort system of indirect illumination, because the pupil expands more and hence does not require the amount of light to distinguish objects that it would under the direct light system, where the pupil tends to contract, due to direct rays from the exposed unit. Therefore, I do not think 3 foot-candles of indirect illumination should be compared with 3 foot-candles of direct illumination.

I might sum up the advantages of indirect illumination for this store as follows: The original installation can be made at small expense; the up-keep is small, consisting only of replacing the lamps occasionally and wiping out the reflector; the general character of the light throughout the store; decrease of nervousness among employees; advertising benefits and many other features might be mentioned.

For the two show windows, size 8 ft. deep and 8 ft. high, I recommend six scoop reflectors for each window. These reflectors are composed of the same material as the indirect lighting reflectors. They are so designed that the light is confined chiefly within the window, and thus most of the light is concentrated on the goods, where it is needed: this is in direct contrast to most window reflectors, which allow a large amount of the light to be wasted on the top, ends and upper back of the windows, and on

the sidewalk. The reflectors are to be placed directly at the ceiling, and as near the front of the windows as possible. Each reflector is to be placed in the center of a 20-in. space; that is, each lamp will be on a 20-in. center. One 60-watt clear bulb tungsten lamp will be required for each reflector. This will make a total of 360 watts per window, or 36 watts per front foot, and about 28 watts at the back of the window.

I do not recommend this arrangement of show window lighting for all windows, as the locality of the window depends largely upon the degree of illumination that is necessary for best results; for example, I would not think of figuring on as high a degree of illumination in a small country town of one thousand inhabitants as I would on a retail street of a large city. In many instances, good results can be obtained by placing scoop reflectors on 3 ft.-centers; whereas on streets of a large city the scoop reflectors have been placed on 18 in.-centers. In conclusion, I might state that I have chosen a window in a town of average size.

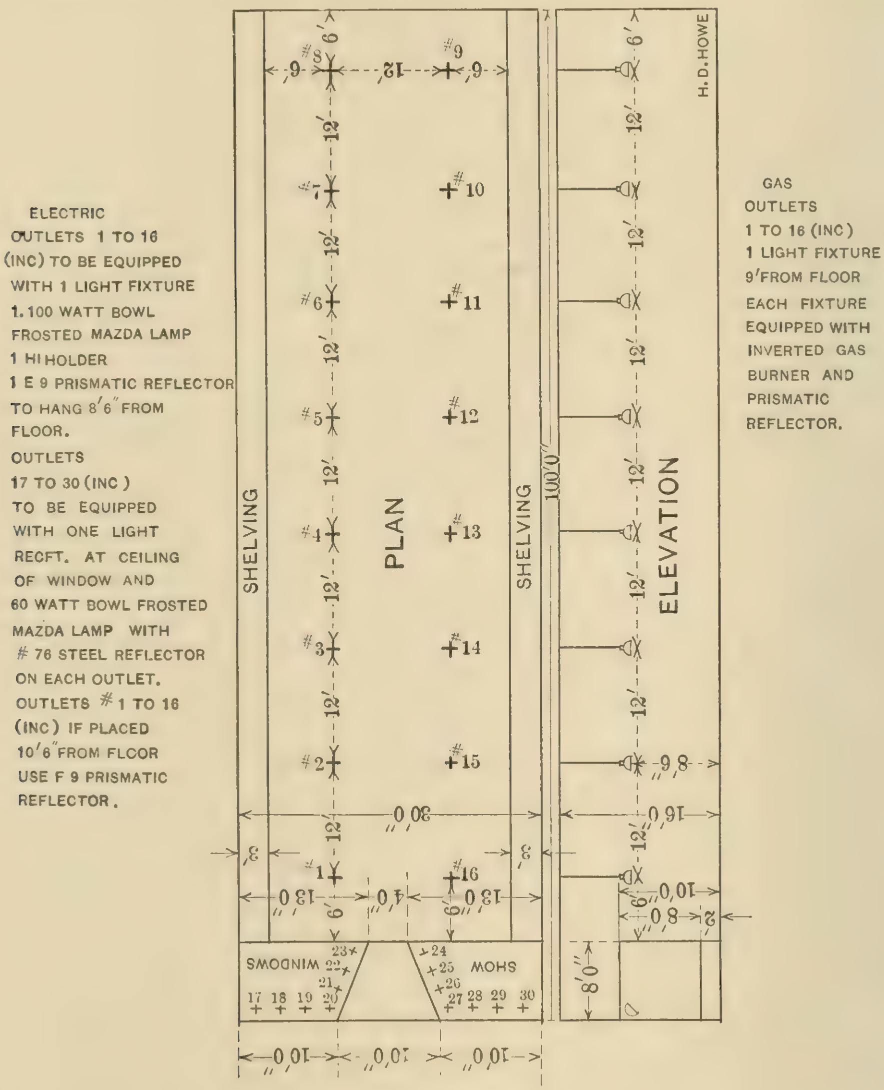
Chairman Scheible:—Mr. H. D. Howe has offered a plan which has the peculiar quality of being suitable for either gas or electric use. His idea is also to arrange the lamps in two rows, with a total of eight lamps in a row, which, in the case of electric light, would be 100-watt tungsten units hung 8 ft. 6 in. above the floor and equipped with prismatic reflectors. If gas were used he would suggest for each of these outlets a single light fixture equipped with a single gas burner and prismatic reflectors.

For the show windows he suggests a series of seven lamps in each window with 60-watt lamps for the electric, bowl frosted, with suitable reflectors. He does not state what he would suggest in the case of gas.

In this plan and several others we have had the advice of using the lamps in two rows owing to the width of the store, although there are some who think a single row sufficient.

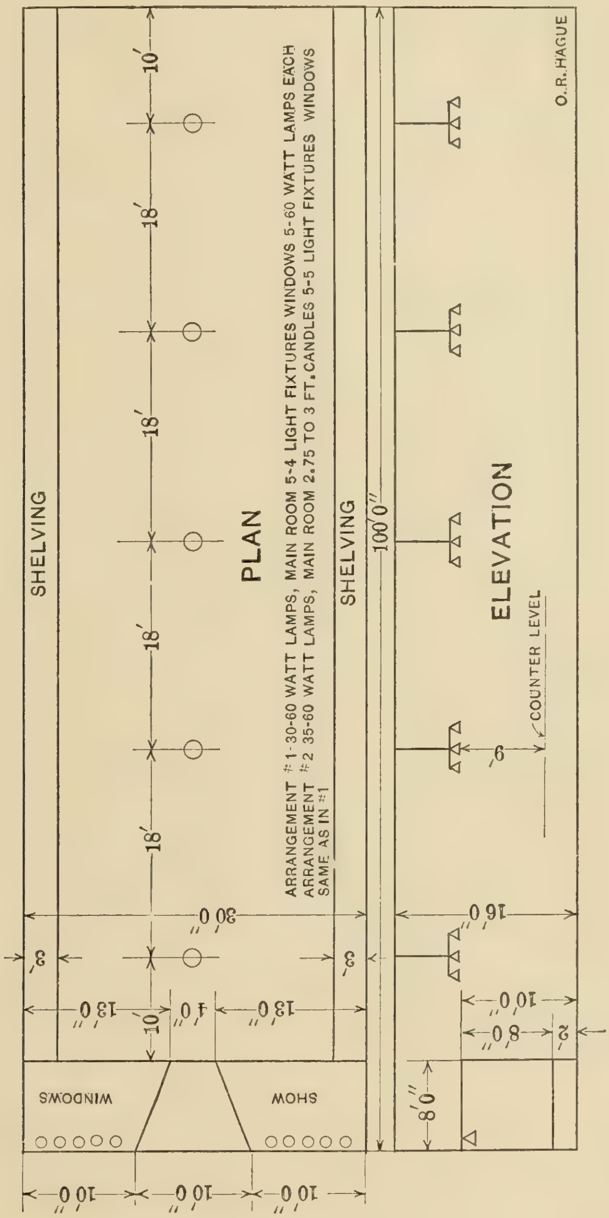
J. P. Smith:—The one I have outlined here is not so much an ideal condition as the ones that have been presented; but it shows that condition as we very often find it; not perhaps as we should find it, but as it is. It might be interesting to know how near this condition the average store comes.

The custom ordinarily followed in a store of this type is to wire it down the center for a single row of light, using five outlets. The common plan would be to have a four-light fixture with 60-watt tungsten lamps, using shades just as the customer might choose. In the windows the plan usually followed



is to put a 60-watt lamp for every 2 ft. of frontage. That gives five lamps for each window. With the 4-light fixture for the store the lamp is placed about 9 ft. above the counter level, and the average foot-candles would be about 2.25, and if you wish to increase this intensity a 5-light fixture is found in the average installation. That would increase the intensity up to

about 2.75 or nearer the 3 foot-candles requested. As has been shown here tonight, it seems that a better distribution can be gained by using single units and stringing them in two rows,



but it seems to be a very hard matter to get the average customer to do that. This store is about 5 ft. wider than the average store of this kind we are called upon to light.

J. R. Cravath:—My plan is a freak. It is something out of the ordinary, and I am not prepared to say that I would recom-

mend it for this kind of store, but it is something to think about.

The plan I propose is a combination of indirect lighting with shaded direct lighting. Indirect lighting is used for general

illumination and this is supplemented by shaded direct lighting which adds to the intensity at the counter level. Under the plan proposed, no lamp filament would be visible to a person looking the length of the store. I have planned to obtain one-half of the 3 foot-candles from the indirect lighting, and the remainder

from the shaded lighting. For the direct lighting, with the reflector proposed, the watts per lumen with lamps and reflectors clean may be as low as 0.16. For the indirect lighting in a store of this kind the watts per lumen would 0.4 to 0.45 with shades and everything clean. To take care of dirt and depreciation I have assumed the figure 0.2 watts per lumen for direct and 0.50 for indirect lighting. To obtain 1.5 foot-candles with direct lighting will require 1.5 by 0.2 or 0.3 watts per square foot. To obtain 1.5 foot-candles with indirect lighting will take 1.5 by 0.5 or 0.75 watts per square foot. The total number of square feet in the store, excluding the shelves is 2,760, and multiplying this figure by the watts per lumen for direct lighting gives 830 watts and for indirect 2,060.

I suggest dividing the store into three equal parts with a cluster of indirect lighting units in the center of each part. Each cluster contains 500 watts in tungsten lamps, either in the shape of two 250-watt or five 100-watt lamps, using distributing reflectors 4 ft. 8 in. from the ceiling. This will reduce 25 per cent. the calculated wattage for the indirect system. For the direct system I propose 12 outlets spaced in two rows, one along the center line of each half of the store. This will increase 25 per cent. the wattage calculated for the direct system. The total wattage, therefore, is 2,700 for the whole scheme.

For the direct lighting, I would use the "bee-hive" reflector, which gives a fairly uniform illumination over a plane extending 35 degrees from the vertical, and very little illumination beyond that limit. This is a single piece of glass, corrugated mirror reflector of high efficiency, and of sufficient depth to cover the lamp except as regards persons standing within a short distance from a vertical line drawn through the lamp. This reflector with a 100-watt lamp will cover uniformly an area the diameter of which is equal to about 1.5 times the height of the lamp. The area which must be covered by each direct lamp must be approximately 15 feet square. Ignoring the corners, which can be done on account of the light given outside of the limits named, these reflectors must be hung 15 divided by 1.5 ft. or 10 ft. above the counters. This will be 13 ft. above the floor. As these reflectors are not ornamental they should be covered either by a brass spinning, or by some type of box fixture. If

desired, art glass can be put into the sides of the boxes, and the silvering removed from the tops of the corrugation, thus letting a little light through to illuminate the art glass.

I used a modification of this same scheme in the Northwestern University track room. The room was about 150 ft. by 200 ft. I think the largest one of its kind in the country, and this particular reflector, I speak of was designed for that purpose. In order to enable them to see balls, etc., a little more clearly I put some indirect lighting in the upper part of each box fixture.

For the show windows I would place poke bonnet reflectors 15 in. between centers, eight in number at the front top of each show window. These windows are very low and a reflector taking but little room vertically is demanded. The depth of the window is also such that the light distribution from the poke bonnet is best suited. The poke bonnet gives nearly as much illumination slightly below the horizontal as it does vertically, which is the requirement in this shape of window. In each poke bonnet I would place two short-bulb 40-watt tungsten lamps.

The suggestion for the interior lighting of the store is not offered as necessarily being the best solution of the problem, but as affording a combination of some of the economy of direct lighting with some of the advantages of indirect lighting as well.

The weakest point in this scheme, in my opinion, is the reflected light from the interior of these reflectors, which is visible to persons standing about 45 degrees from a vertical line through the lamp. As a whole, however, it is an interesting possibility in illuminating engineering.

The room we are in here tonight represents another very interesting engineering problem. There are two sky lights. Reflectors above the sky lights are tipped to throw the light forward and keep it out of your eyes as much as possible. There is quite a large loss due to absorption of light by the sky light. Nevertheless I think it is worth while to stand this loss to have the lights so well shaded and diffused.

A. L. Eustice:—Although I have not prepared a plan of an equipment for this store, I would suggest that the following solution. Owing to the location and height of the shelving, I do not suppose it is proper to consider its area; so that the dimensions to consider are 92 ft. by 24 ft., or 2,208 square feet. In this

solution it is proposed to employ Nernst lamps, and from experience, I would recommend an expenditure of approximately 1-watt per square foot of various single glower Nernst lamps in a distributed system for an average mean illumination of three foot-candles. Investigation has shown that the average commercial efficiency of such system when operated under normal conditions of regulation and maintenance is approximately 0.33 watts per lumen in a room such as is the subject under consideration. The initial illumination would be slightly in excess of three foot-candles.

As to location of units, it would be very similar to the one suggested by Mr. Henninger.

First, I would place a row of eight units along a line at regular intervals over the counter approximately 8 inches from their outside on each side of the room, and in view of the fact that tables for displays will be placed in the center, I would supplement the two rows by a third row down the center of one-half the number of lamps. This would make four equal imaginary bays of five units each, or 20 lamps. Hence the size of lamp would be 2,208 divided by 20, or 110 watts each. This is the wattage of the standard 110-watt single-glower lamp; so 20 lamps of this type would be used, equipped with the regular alabaster globes.

The elevation should be about 1 ft. below the top of the shelving, which I suppose is about the same as in the plan referred to.

For the window illumination I would recommend the use of 5 100-watt lamps, spaced every 2 ft. along the front only, using a reflector somewhat similar to the sketch I have here, which is designed so that the light is greatest at approximately 450 and also cut off very abruptly at the base of the window. This confines all the light to the display instead of wasting a large quantity on the sidewalk, which is so common with most window systems. This lay-out would give a mean illumination of approximately 10 foot-candles in both planes of the window, *i.e.,* the vertical or back and the bottom.

I do not think it is good practice to place lamps in the side windows where they are placed at an angle to the entrance for lamps in such position, while they would give a somewhat higher

intensity, would detract from the display; they would cast direct light into an observer's eye and be the prominent feature of the display.

H. E. Niesz:—In the commercial end of the business we may have plans for lighting that would meet with the engineer's ideas, but the question in mind of the customer is the cost of installation. While there may be ideal systems, the question of wiring and the cost of the new installation would probably have more weight with the customer than an ideal installation. Although we are in the business to give the customer the best thing possible, it is sometimes pretty hard to tell just what the best thing is because we do not agree among ourselves. Therefore, we must combine theoretical ideal illumination with the practical, as well as take into consideration the financial side of the proposition, which sometimes may not result in the ideal but meets perfectly the ideas and requirements of the party buying the light.

J. G. Henninger:—With reference to the depreciation in candle-power of lamps due to dust and dirt, I have investigated a number of cases and can say that it varies entirely according to conditions. For instance, in the business section of a town or city it would be considerably greater than in the outlying districts. In some cases I have looked into, I have found that in the down-town district the depreciation over a period of four, five, or six months in some instances brought the resultant illumination intensity down to about 70 per cent. of the initial value. As has been said before, it would depend on the manner of use, where installed and how often cleaned. The glassware and lamps should be kept just as clean as the show cases. If the floor is properly sprinkled, the depreciation, due to dust and dirt, would be considerably lessened.

My idea of the type of window lighting most nearly approaching the ideal would be that similar to stage lighting, the results of which could be seen without the presence of the lighting units being felt. Another thing that is not often given proper consideration is the background. In a store window which I saw the other day the lighting units were placed along the transom bar and provided with opaque reflectors. The woodwork in the window back and ceiling was finished in pearl gray. The rear of

the window up to a point 5 or 6 ft. above the floor was covered with plush curtains of a light gray color. The effect was beautiful. The window had the appearance of being full of light, although this fullness was not in any way objectionable. There was no glare. Every article on display stood out in perfect detail.

A. L. Eustice:—While we are on the subject of dust and dirt on glassware and lamps, I would like to say a word or two. Personally, I have done a great deal of work along these lines in collecting data in every part of the country on installations employing all types of units and reflectors in all sorts of locations, and I believe if people realized the waste from this point alone more care would be given their installation. I have found that out of about 1,000 tests that the average of all tests would indicate a mean depreciation of something like 10 per cent. for each month.

Another thing which I think is always under-estimated is the fact that in laying out a proposition such as we have had here tonight, it is almost universal for people to figure on a definite efficiency for a type of unit without considering the physical surroundings The physical condition of the unit itself, the color and general nature of the location of the unit and the like have much effect on the operation of an installation as the efficiency of the unit employed.

A paper presented at a meeting of the New York Section of the Illuminating Engineering Society, New York, May 12, 1910.

A HIGH EFFICIENCY REFLECTOR FOR STREET LIGHTING.

BY CLAYTON H. SHARP.

The problem of the satisfactory illumination of public streets and highways is one which we shall always have with us. The extent of the streets requiring illumination is practically limitless and the demand for more light in unceasing. The brilliant blaze of Broadway which represents the maximum of street illumination to-day may be the standard of First Avenue a few years hence. Residential streets are far better lighted to-day than they were in the days of the open gas flame, but the illumination is still insufficient. Country highways which a few years ago were in Stygian darkness are now outlined by street lights, but with the increasing density and speed of highway traffic, the need of a more effective highway illumination is becoming more and more imperative. In the fact of an undoubted demand for higher degrees of illumination and for continuous extensions of lighting systems to streets now unlighted, the most important question which arises is that of economy. An economical street lighting system can be realized in any particular case by the selection of such illuminants as shall be most economical, by the proper location of these illuminants and finally by the most effective utilization of the luminous flux available.

Great progress has been made in the last ten or twelve years in the production of economical illuminants for street lighting. The introduction of high pressure mantle burners, of tungsten lamps and of flaming arc lamps has been of great importance to the art of economical street illumination. In many respects, the most significant and important advance has been in the production of the tungsten lamp, the advent of which opens up a field in street lighting which was formerly entirely inaccessible to the electric supply company and which has enormous possibilities. With either the multiple burning or the

series burning tungsten lamp, unnumbered miles of residence streets and of suburban highways can be given an economical illumination which formerly were either unlighted or were the exclusive domain of less manageable and less powerful illuminants.

In the production of devices aiding in the proper distribution of luminous flux for the economical lighting of streets, relatively little progress has been made. In interior illumination, this is not so. Within the last few years the greatest attention has been given to the question of proper shades and reflectors so that to-day almost any requirement can be met by appliances actually on the market.

The problem of the design or reflectors and globes for street lighting is quite different from that for interior illumination, although this difference has seldom been recognized. For the illumination of interiors, it is desirable that a certain flux of light reach the ceiling of the room. The ceiling must be illuminated, and sends back a proportion of such flux to participate in the useful illumination of the room. In the case of street illumination, all flux leaving the fixture above the horizontal plane is absolutely wasted. Therefore, a street lighting reflector should direct as nearly as possible all luminous flux in directions below the horizontal. Furthermore, in interior illumination, the distribution of flux about the vertical axis of the lamp with its reflector, may usually, without detriment to efficiency, be symmetrical. In the illumination of streets, the case is quite different. The crosswise dimension of a street may be taken as of negligible importance as compared with the lengthwise dimension. Therefore, if the distribution of flux be symmetrical, an undue proportion of the flux is directed toward the sides of the street. The distribution must be unsymmetrical, a far greater proportion of flux being directed lengthwise of the street than crosswise of the street.

The requirement of street illumination is that the roadway and objects in the same shall be illuminated to a degree which shall at every point exceed a certain minimum value. What results from the ordinary arrangement of lamp alone or lamp with symmetrical reflector is that, in the vicinity of the lamp, the

street is excellently illuminated, but this illumination falls off rapidly with the distance, so that at a point midway between lamps it has a relatively very low value. At the same time each lamp distributes crosswise of the street as much light as lengthwise, and only a small proportion of this light is effective in lighting the street itself, the major part being wasted on the roadside. Thus the ordinary system of street illumination is very inefficient from two causes, first in that only a small percentage of the total luminous flux is incident on the surface to be illuminated, and second in that the distribution of the flux so incident is such that the illumination in the immediate vicinity of the lamps is unduly high, while midway between lamps the minimum illumination, which is by far the most important factor to be considered is far too low.

The reflector and lighting fixture herewith described represent the results of an endeavor to obviate these disadvantages of the ordinary system of street lighting and thereby to obtain a more economical and more uniform illumination. The problem was to collect the luminous flux ordinarily wasted in the upper hemisphere and toward the sides of the street and to redirect that flux so that it would be incident on those parts of the street where it was most needed, namely in the region midway between the lamps. This result should be accomplished without interferring with the natural illumination on the street surface from the lamp directly, so that in case the device became inoperative or operated badly, as by the accumulation of dirt, the illumination would at least not be any worse than if the device were absent entirely.

It is clear that stray light could be collected and redirected so as to illuminate the regions midway between lamps by the use of a parabolic mirror with the lamp at the focus. But this arrangement would cut off the necessary light near the lamp post and hence would be impracticable. This difficulty could be met by cutting away the lower portion of the reflector. But this arrangement is not yet all that is desired because it directs the light in only one direction instead of two directions 180° apart as required. This condition may also be met if the parabolic reflector is cut through vertically in the focal plane and a simi-

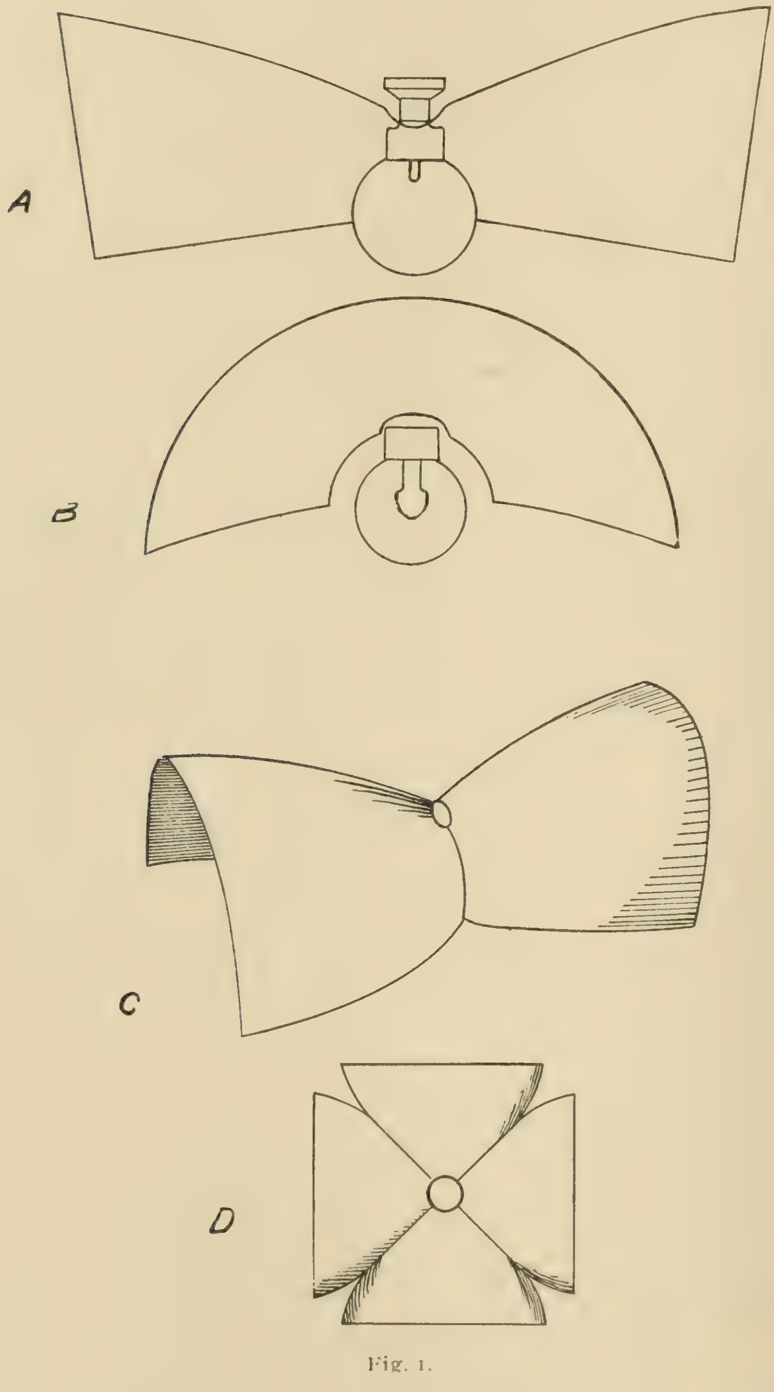


Fig. 1.

lar reflector also with its lower half cut away is placed back to back with the first.

This results in a structure which does not obstruct the natural illumination of regions near the lamp and which by redirecting light otherwise wasted builds up the illumination in the dark parts of the street. Across-sectional view of such a reflector is given in Fig. 1, A. It will be seen that the semi-paraboloids are inclined to each other so that the two reflected beams will fall on the street surface at the required distance from the lamp post. Fig. 1, B shows an end view of the reflector and lamp and Fig. 1, C gives a perspective view of the exterior.

An objection may be made to this arrangement on the grounds that a parabolic mirror throws a nearly parallel beam of light. Consequently the effect of the proposed arrangement would be to illuminate only a small area of the street by the rays coming from the mirror; that is, at a point midway between the lamps there would be a little bright patch which would amount to nothing as far the general illumination goes, while the surrounding portions of the street would be left in darkness as before. This objection would be a very valid one provided we had a very small source of light in the focus of the mirror. Then the effect would be that of a searchlight beam. What we actually have in practice with the tungsten lamp is quite an extended source. The result of this is that the beam of light is a divergent one and at the distance where it is effective, it covers a considerable area. The angle of divergence of a beam of this character is equal to the angle which is subtended at the mirror by the source of light. It is found in practice that this angle is sufficient to cause reflected rays to cover all the area of the street surface which is required.

The idea which is developed above of using two semi-parabolic mirrors pointing in opposite directions, may evidently be extended to include three or four or more. For example, at the intersection of streets, a reflector would be used which has the form shown in Fig. 1 D. It is clear that this reflector would not be so effective in any one direction as is the two direction reflector, because the luminous flux is divided by four rather than by two. Still the gain resulting from the use of this reflector

would undoubtedly be very considerable. The most effective form being the two reflector form, and there being less waste light with such reflectors as are commonly in use in the case of lamps placed at the intersection of two streets than there is in the case of lamps placed in the middle of a block, the two direction reflector is the one which has been given the chief attention up to the present time.

The first reflector which I had made was constructed of zinc. The zinc was spun into the form of a paraboloid of revolution cut through the focal plane. This paraboloid was afterward cut in two lengthwise and the halves were mounted in the way shown in the diagram. The interior of the paraboloid was brightly burnished and made a very good reflecting surface. In the proper position in this reflector a 50 candle-power Gem lamp was mounted and the fixture was raised to a height of approximately 15 feet above the street. The normal illumination produced at different distances by the reflector was then measured by a portable photometer and was compared to the illumination which would have been produced by the lamp alone. The latter was however, excepting quite close to the lamp post, too small to be measured with any degree of accuracy. This test was carried on on a quiet residence street which was very badly illuminated by series incandescent lamps placed some 300 ft. apart. The illumination which they produced was so small as to be negligible when taking the measurements. The illumination produced by the 50 candle-power lamp with reflector was striking in its effect on this street. One person meeting another approaching the light at a distance of 500 ft. could recognize the other's features. The normal illumination values obtained in this test are given in the curves in Fig. 2. Points are put on the curves to show the standard values adopted for the magnetite arc and for the 6.6 amp. d.c. enclosed arc, as adopted by the National Electric Light Association. It will be seen that both of these values are considerably exceeded by the 50 candle-power incandescent lamp with reflector.

The results of this test were so encouraging that the work was taken up of developing a commercial form of street lighting fixture embodying this reflector. In this part of the work, I

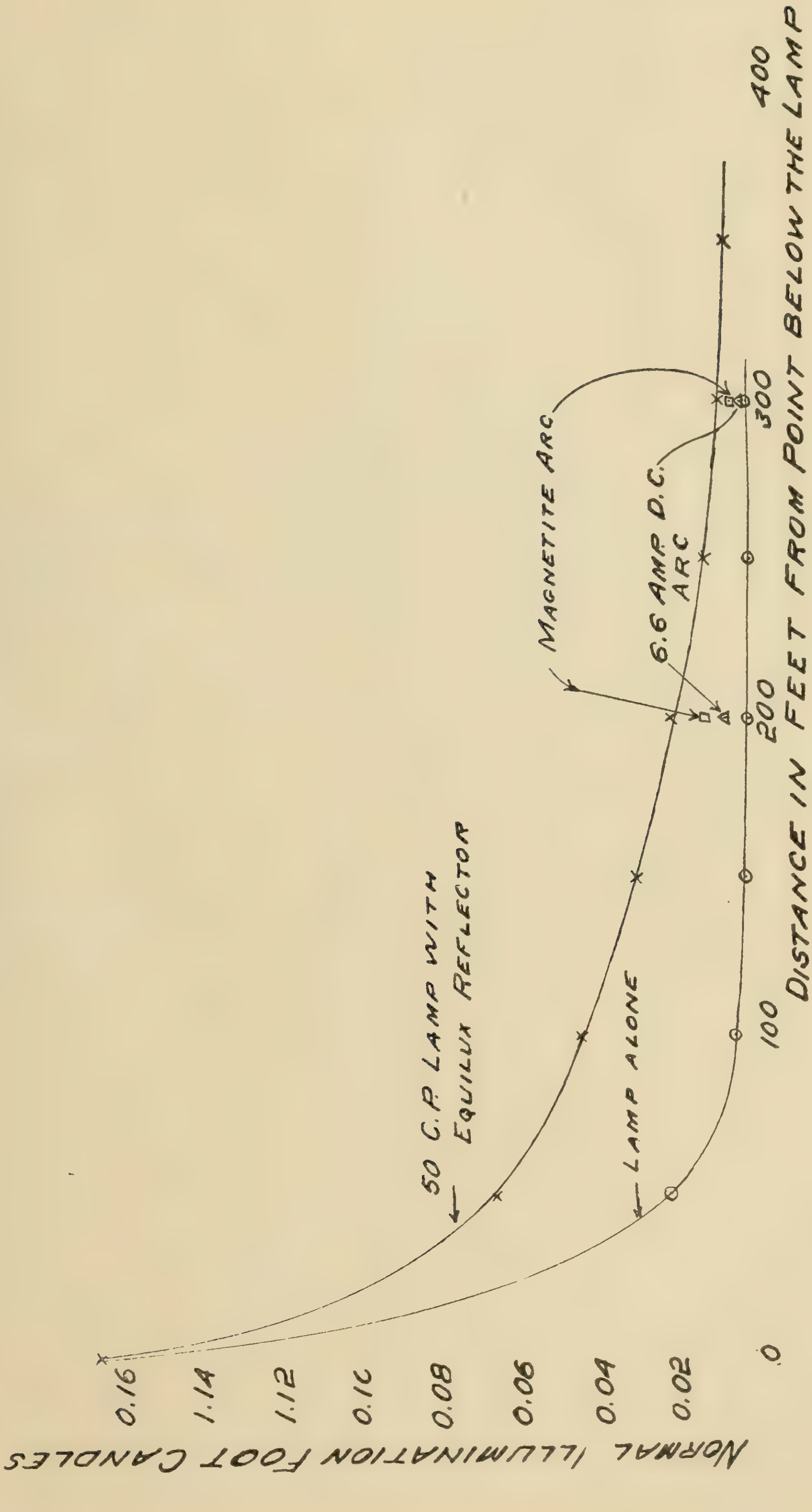

NORMAL ILLUMINATION FOOT CANDLES
0.16
1.14
1.12
0.10
0.08
0.06
0.04
0.02
0
100
200
300
400
DISTANCE IN FEET FROM POINT BELOW THE LAMP
50 C.P. LAMP WITH EQUILUX REFLECTOR
LAMP ALONE
MAGNETITE ARC
6.6 AMP. D.C. ARC

Fig. 2.

have enjoyed the invaluable co-operation of Mr. S. G. Rhodes, Engineer of the Street Lighting Dept. of the New York Edison Co., and of his very efficient assistants. To the efforts of Mr. Rhodes is largely due the successful form in which the lighting fixture now is found. The typical form of this fixture for incandescent lamps, which is patented, is shown in Fig. 3. To

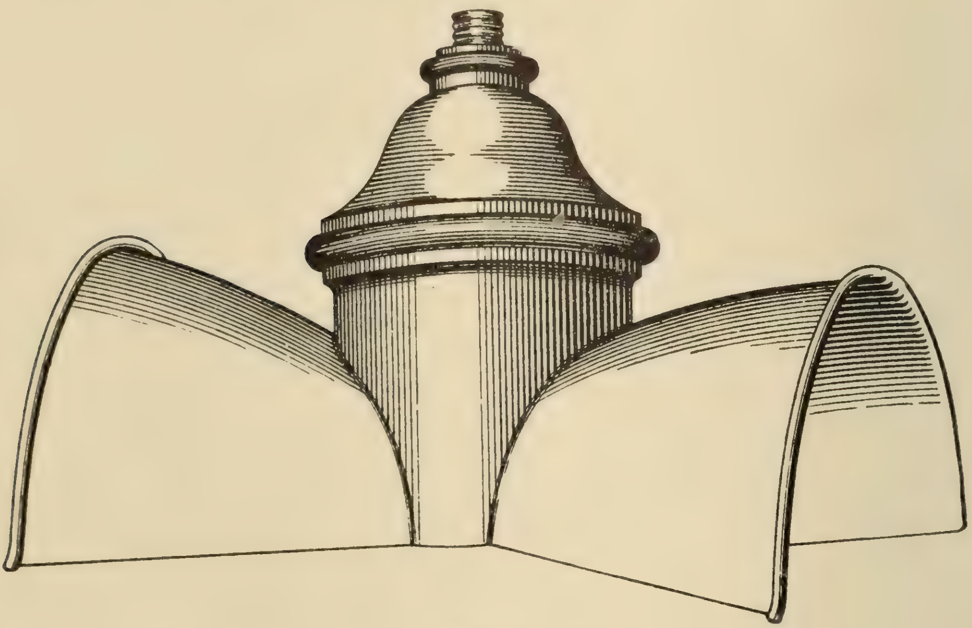


Fig. 3.

this fixture I have given the name "Equilux" which is descriptive of its purpose.

In the fixtures so far made, the reflectors have been enameled white on the interior. This enamel finish has the great advantage of being permanent and easy to clean. It has not however the very high reflecting power of a planished metal reflector, and consequently is considerably less efficient in increasing the illumination. The planished metal reflector is open to the objection that the light from it is very intense and that the glare is somewhat blinding. This is simply another way of saying that it is delivering a very powerful beam of light and that it is very efficient in doing the work for which it is intended. Any device whereby the glare is diminished at the same time diminishes the efficiency. The white enameled reflector gives less glare; it also gives less powerful directed

beams, although the total light from it is probably nearly as great. It is necessary therefore in choosing reflectors of this kind to weigh the advantages of lack of glare and ease of maintenance of the white enameled reflector against the very high efficiency of the polished metal type.

A number of temporary installations of these reflectors have been made and some permanent ones. The following gives the results of illumination tests made by the Electrical Testing Laboratories on two of these installations.

In the case of the first installation there were five Equilux reflectors with series tungsten lamps, and on the same street five reflectors of the flat round type with flutings, such as are often used, the lamps being similar. The spacing of the poles was about 100 ft. and the height of the lamps from the ground about 18 ft. In the second installation, which was made on what was practically a country road, the spacing of the poles was 130 ft. and the height of the lamps from the ground 15 ft.

With this installation, also, illumination tests were made under comparable conditions using the Equilux reflector and a standard round reflector. The results of the tests on the first installation are shown in the curves of Figs. 4 to 7. Those of the second installation in Figs. 8 to 10. It will be seen that the Equilux reflector was effective in increasing the illumination in those parts of the street where it is naturally deficient and that the percentage increase was quite a notable one in those regions.

An unexpected result was that the illumination directly below each lamp was also somewhat higher, indicating the large amount of diffused reflection from the white enameled surface. This diffused reflection is a cause of a loss of efficiency of the Equilux reflector as far as its own particular function is concerned of increasing the illumination midway between the lamps. It is upon this feature, however, that the absence of glare from the reflector depends. The second installation tested showed a result which was considerably inferior to that of the first installation. The reason for this deficiency was found in the character of the enamel on the Equilux reflectors, and being simply an incident of the manufacture, should not be taken as detracting from the possibilities of the type. Even with the inferior enamel

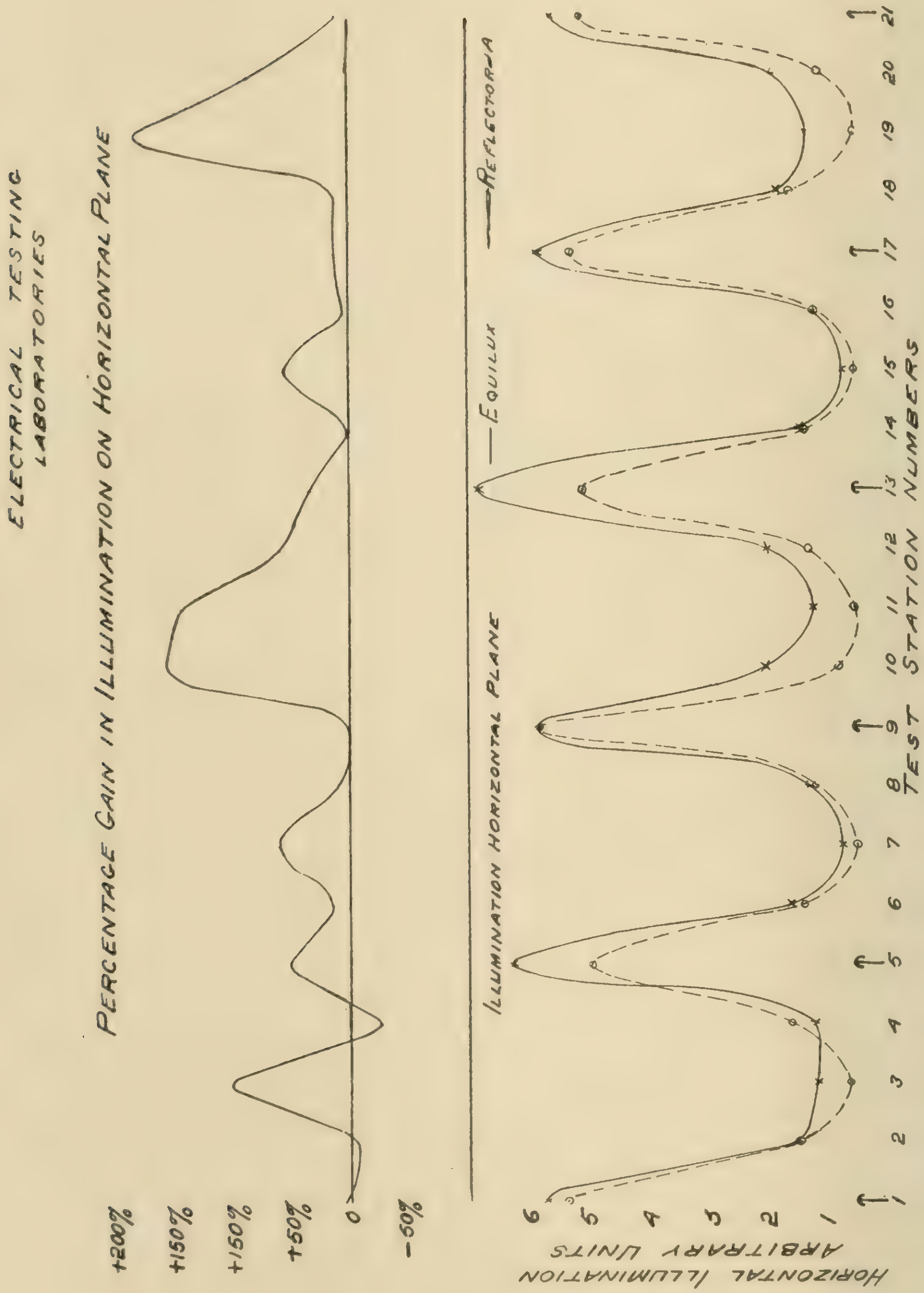

ELECTRICAL TESTING LABORATORIES
PERCENTAGE GAIN IN ILLUMINATION ON HORIZONTAL PLANE
+200%
+150%
+150%
+50%
0
-50%
ILLUMINATION HORIZONTAL PLANE
— EQUILUX
— REFLECTOR
HORIZONTAL ILLUMINATION ARBITRARY UNITS
TEST STATION NUMBERS

Fig. 4.

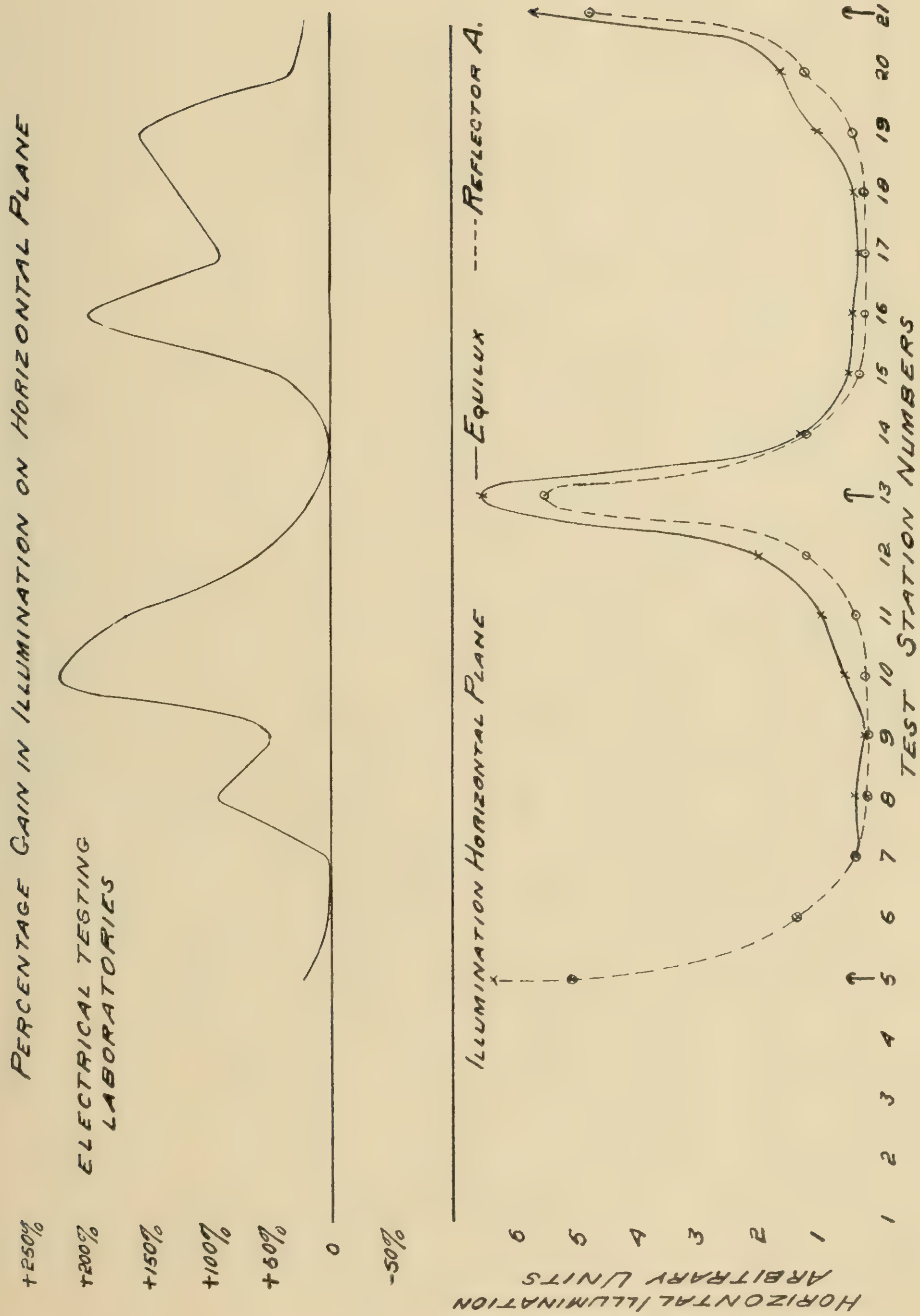

PERCENTAGE GAIN IN ILLUMINATION ON HORIZONTAL PLANE
ELECTRICAL TESTING LABORATORIES
+250%
+200%
+150%
+100%
+50%
0
-50%
ILLUMINATION HORIZONTAL PLANE
— EQUILUX
- - - REFLECTOR A.
HORIZONTAL ILLUMINATION ARBITRARY UNITS
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
TEST STATION NUMBERS

Fig. 5.

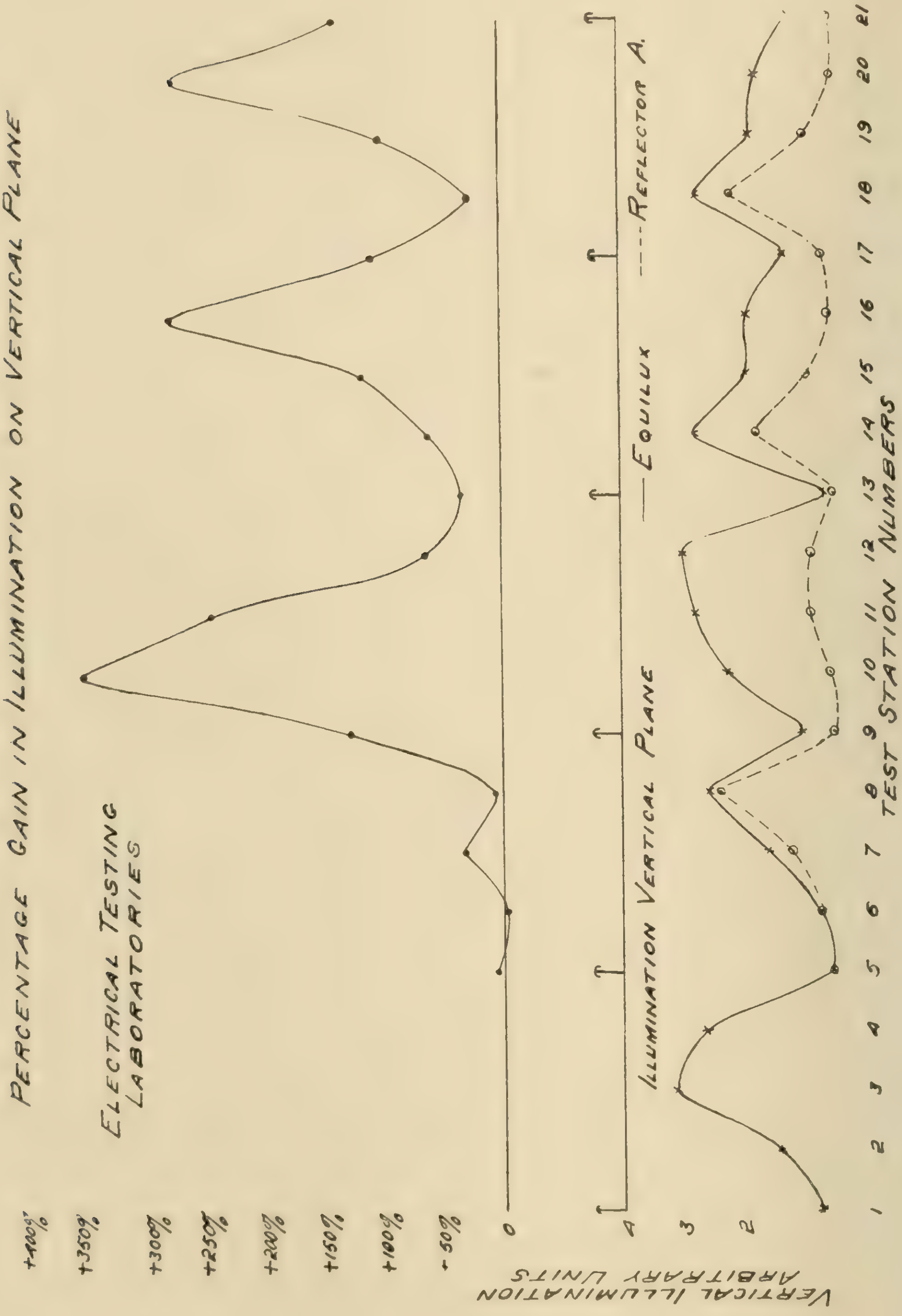

PERCENTAGE GAIN IN ILLUMINATION ON VERTICAL PLANE
ELECTRICAL TESTING LABORATORIES
+400%
+350%
+300%
+250%
+200%
+150%
+100%
+50%
0
ILLUMINATION VERTICAL PLANE
— EQUILUX
--- REFLECTOR A.
4
3
2
VERTICAL ILLUMINATION ARBITRARY UNITS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
TEST STATION NUMBERS

Fig. 6.

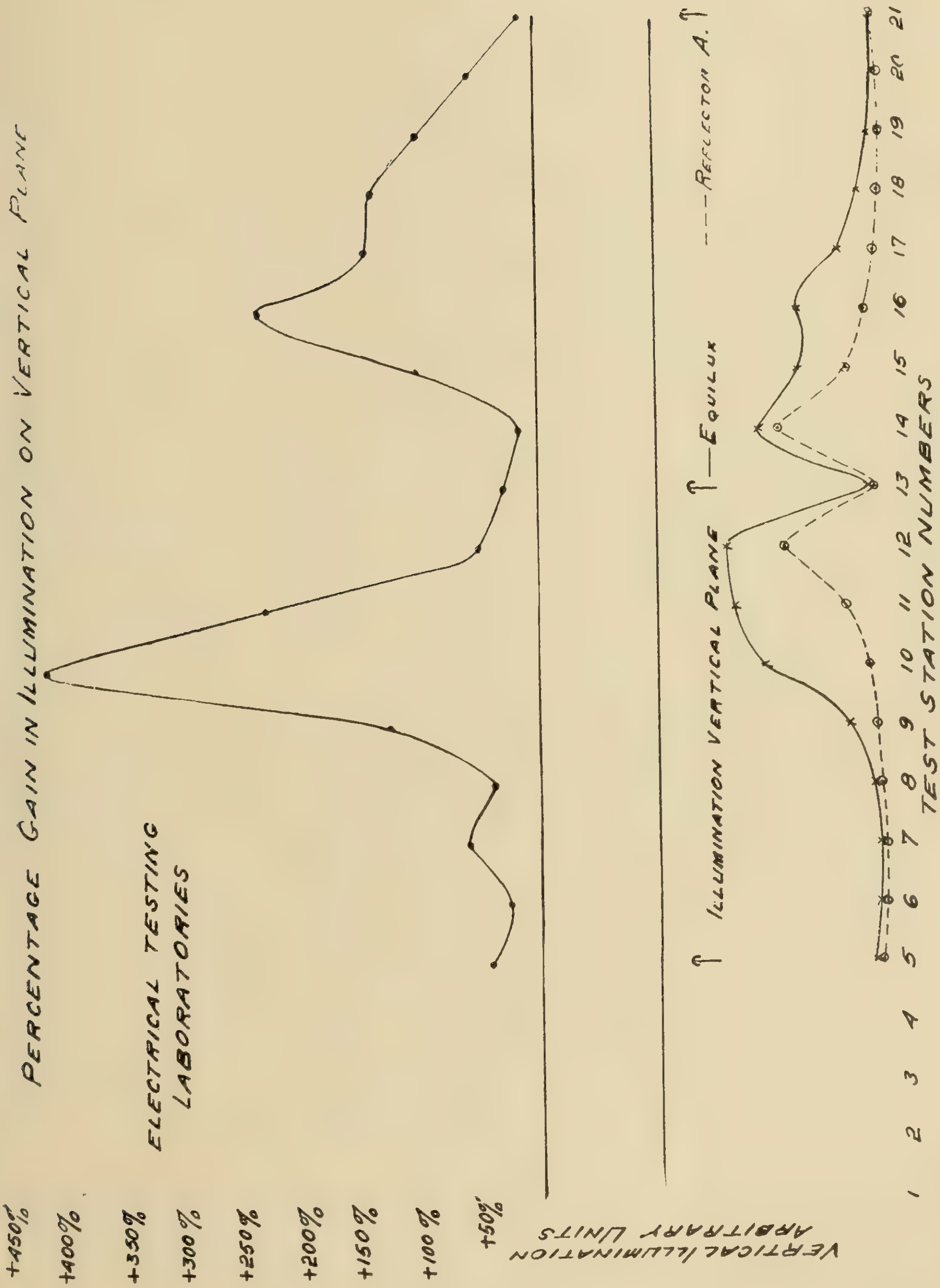

PERCENTAGE GAIN IN ILLUMINATION ON VERTICAL PLANE
ELECTRICAL TESTING LABORATORIES
+450%
+400%
+350%
+300%
+250%
+200%
+150%
+100%
+50%
VERTICAL ILLUMINATION ARBITRARY UNITS
ILLUMINATION VERTICAL PLANE — EQUILUX
--- REFLECTOR A.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
TEST STATION NUMBERS

Fig. 7.

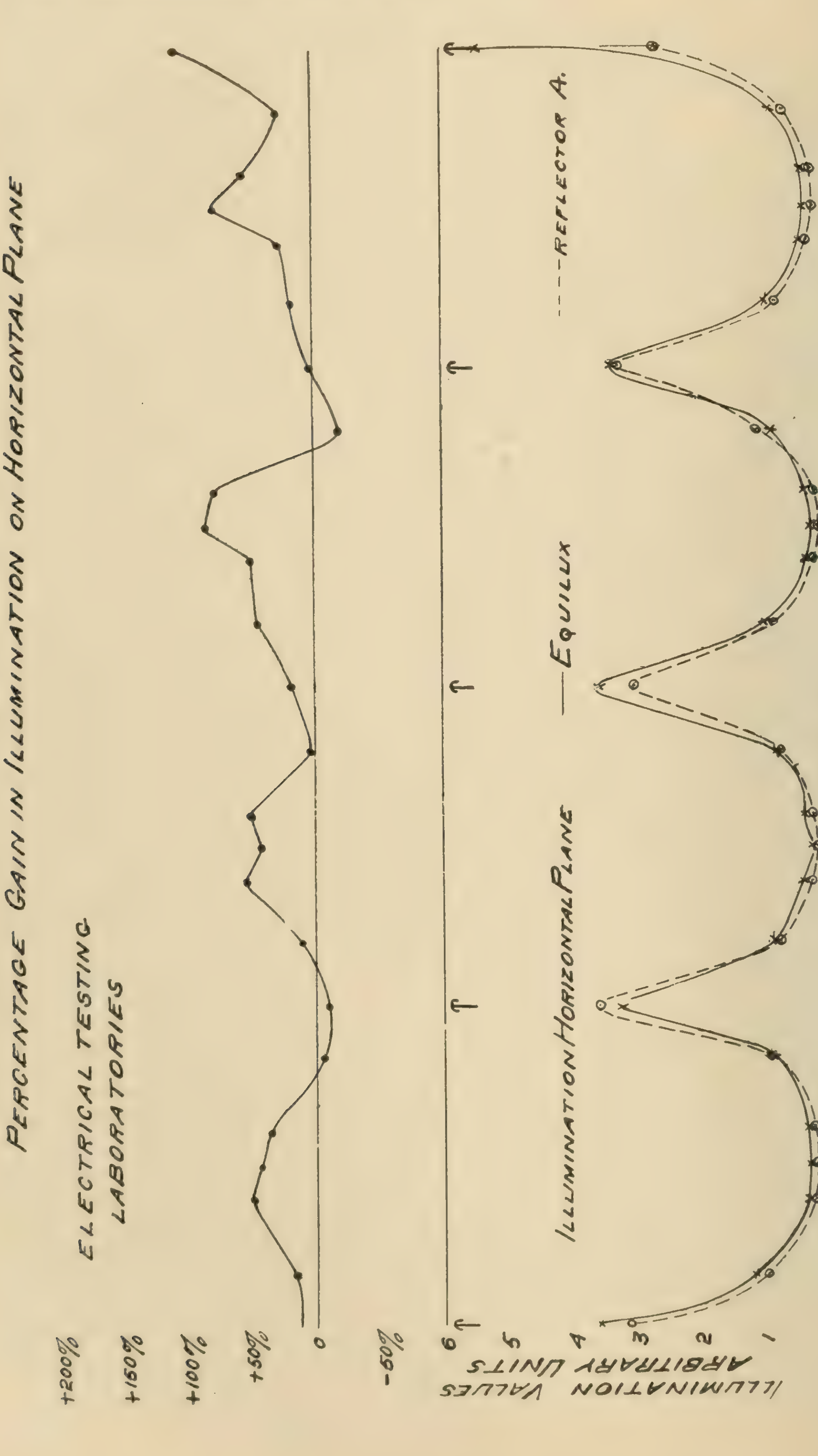

PERCENTAGE GAIN IN ILLUMINATION ON HORIZONTAL PLANE
ELECTRICAL TESTING LABORATORIES
+200%
+150%
+100%
+50%
0
-50%
6
5
4
3
2
1
ILLUMINATION VALUES ARBITRARY UNITS
ILLUMINATION HORIZONTAL PLANE
— EQUILUX
--- REFLECTOR A.

Fig. 8.

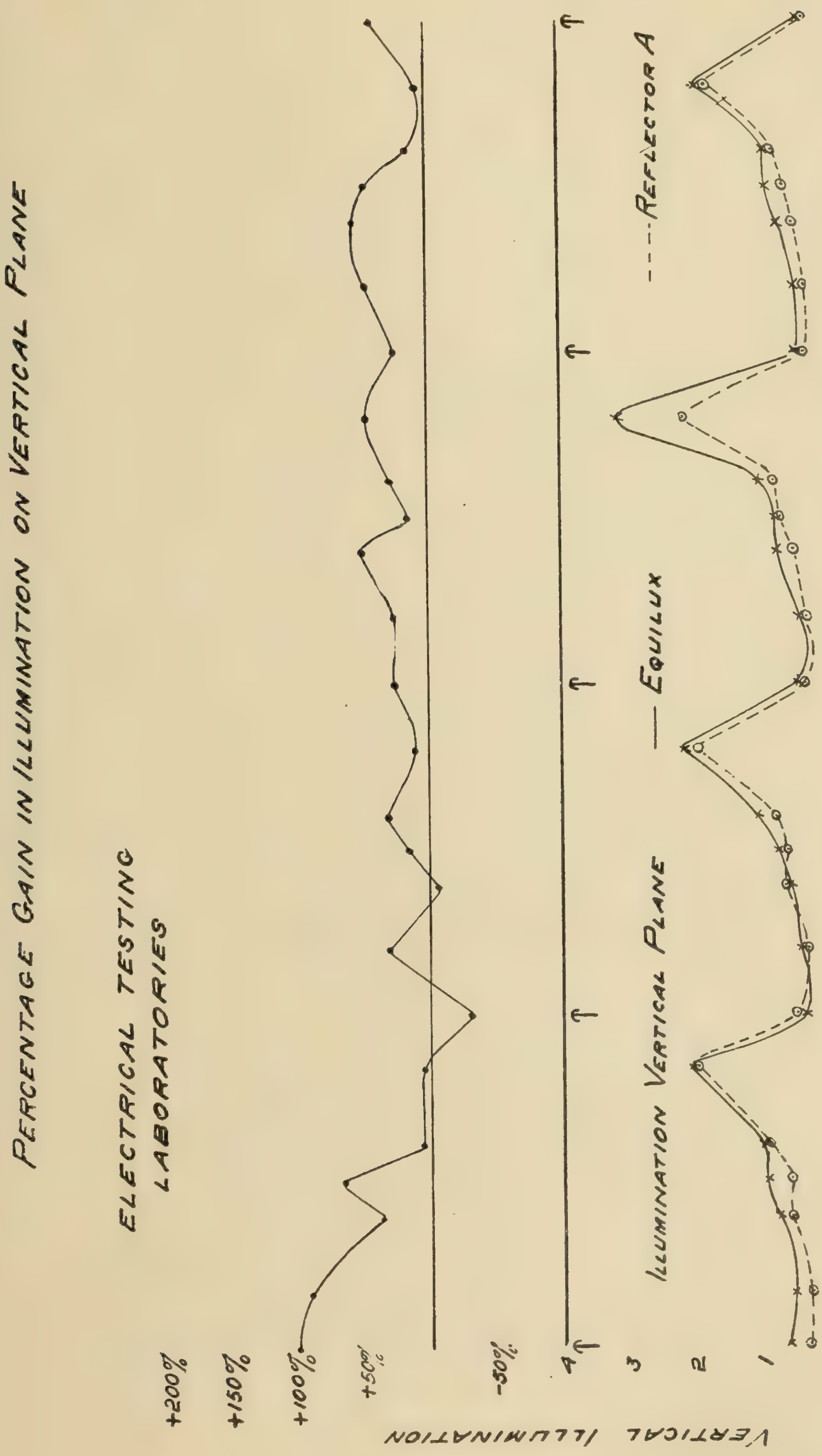

PERCENTAGE GAIN IN ILLUMINATION ON VERTICAL PLANE
ELECTRICAL TESTING
LABORATORIES
+200%
+150%
+100%
+50%
-50%
4
3
2
1
VERTICAL ILLUMINATION
ILLUMINATION VERTICAL PLANE
— EQUILUX
--- REFLECTOR A

Fig. 9.

the increase in illumination in the regions where the light is most needed amounted to something like 50 per cent. This means that replacing the ordinary type of reflector with Equilux has much the same effect as replacing the lamps by others consuming 50 per cent. more energy. This result in itself is worth attaining, but as indicated by the other tests, by no means represents the real possibilities of the new reflector. It is safe to say that with the Equilux reflector a substantial gain of 100 per cent. in the effective illumination can be obtained with the

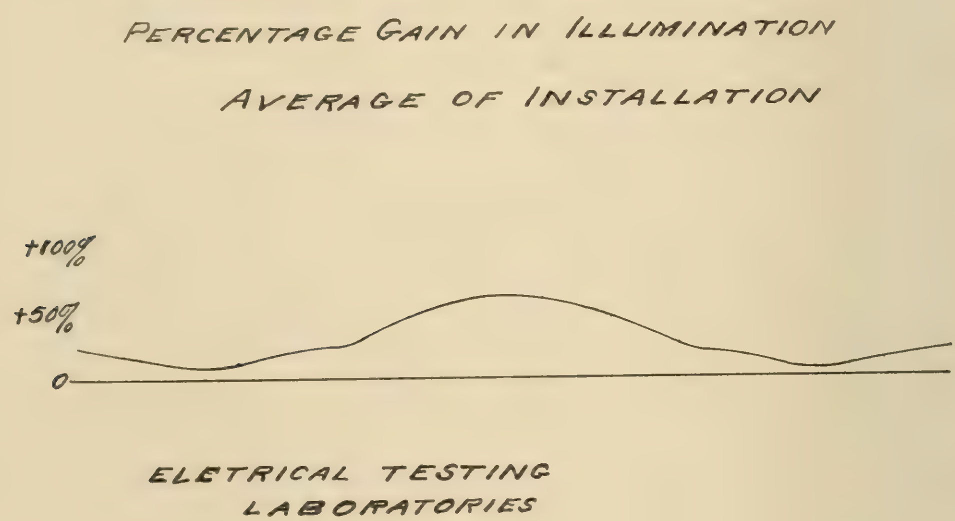


Fig. 10.

enamel type, whereas with the polished metal type, there should be no difficulty in increasing the effective illumination two or three hundred per cent.

The polished metal type is of particular applicability to the illumination of country highways where for reasons of economy it is necessary that lights be placed at very considerable distances from each other. Then by the use of the polished metal Equilux reflector and such incandescent lamps as are ordinarily used for the purpose at the present time, a very acceptable highway illumination can be obtained with but ten lamps to the mile. As has been said, the glare from this polished metal reflector is objectionable. However, it should be distinctly understood that this glare is not as great as is the glare from an arc lamp with clear globe, whereas the illumination produced

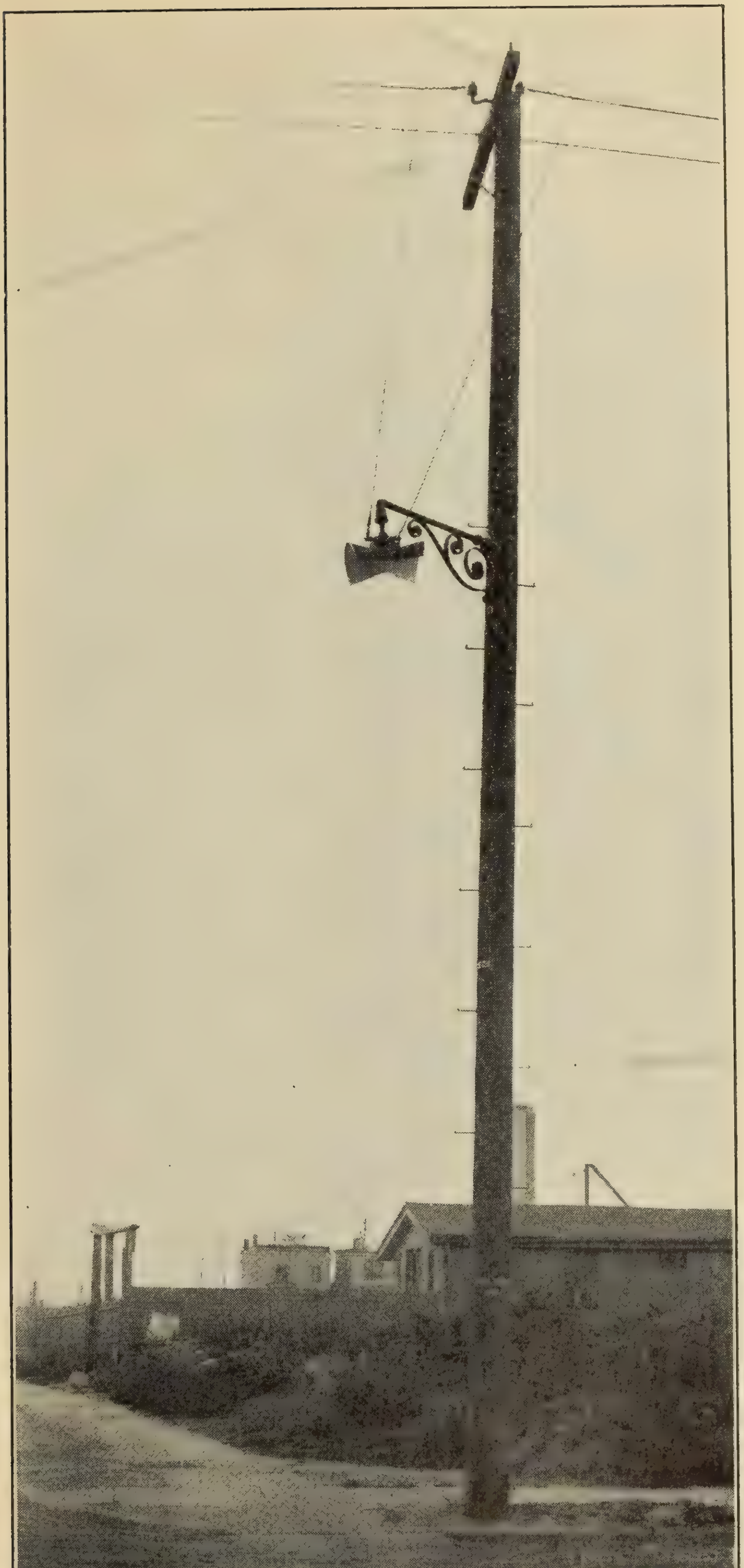


Fig. 11.

with an 80 watt tungsten lamp with a polished metal reflector is at least comparable with that obtained with the ordinary type of arc lamp consuming four or five times the energy. Moreover, where shade trees do not interfere too greatly, tungsten lamps with polished Equilux reflectors can be mounted at such an elevation above the road surface that the light does not fall

Fig. 12.

too directly into the eyes of travelers. This would require simply a reflector with a greater angle between the two halves. The efficiency of the reflector is so great that the light would be directed where required on the roadway with comparatively little loss due to the increased elevation.

Certain forms of street lighting fixtures for incandescent lamps, in which the reflector has been incorporated, are shown in Figs. 11 to 15. The appearance of these fixtures is undoubtedly somewhat odd, but one soon grows accustomed to their strangeness and they are by no means displeasing. To the engineer, the obvious efficiency of the reflector stamps it with the

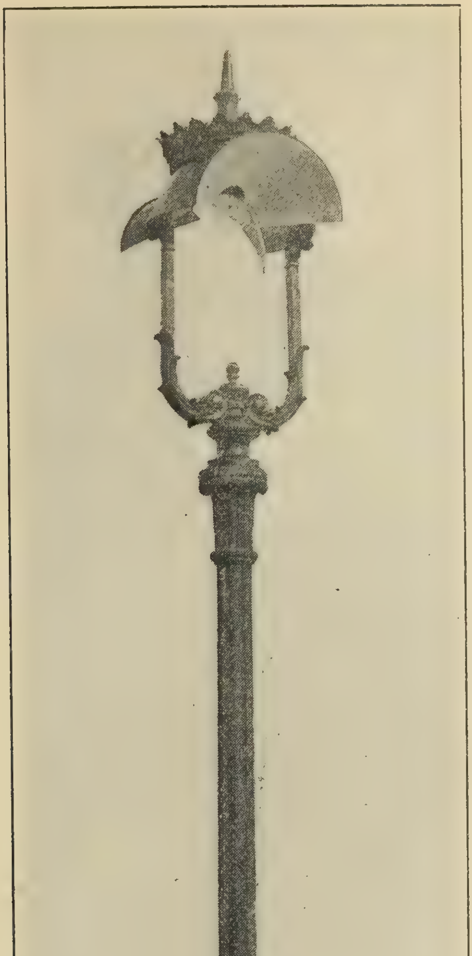


Fig. 13.

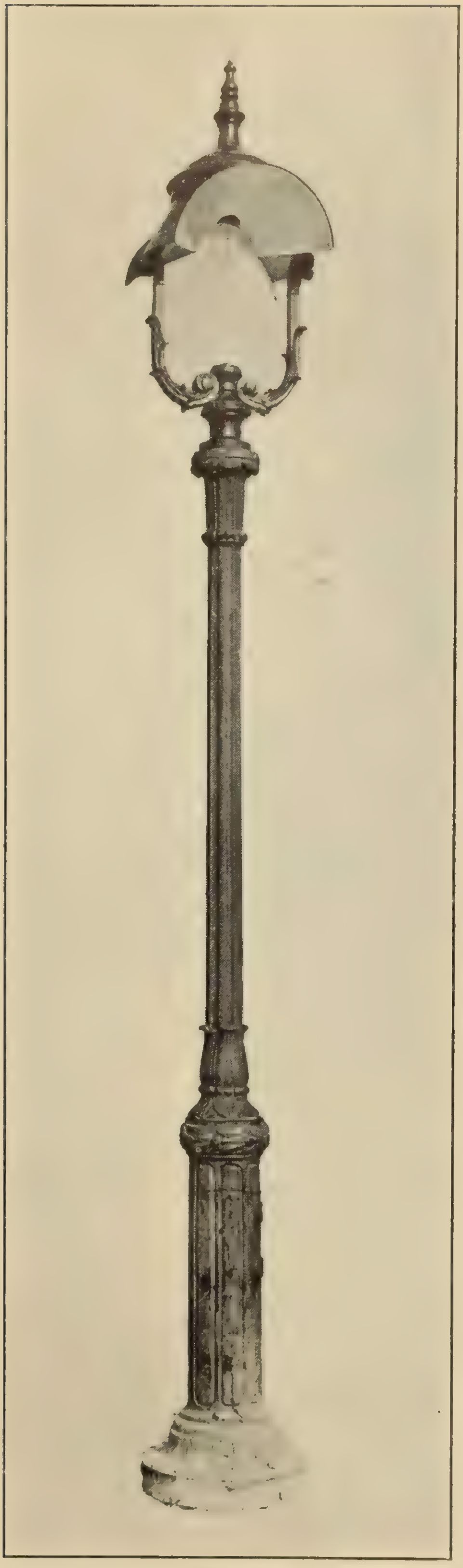


Fig. 14.

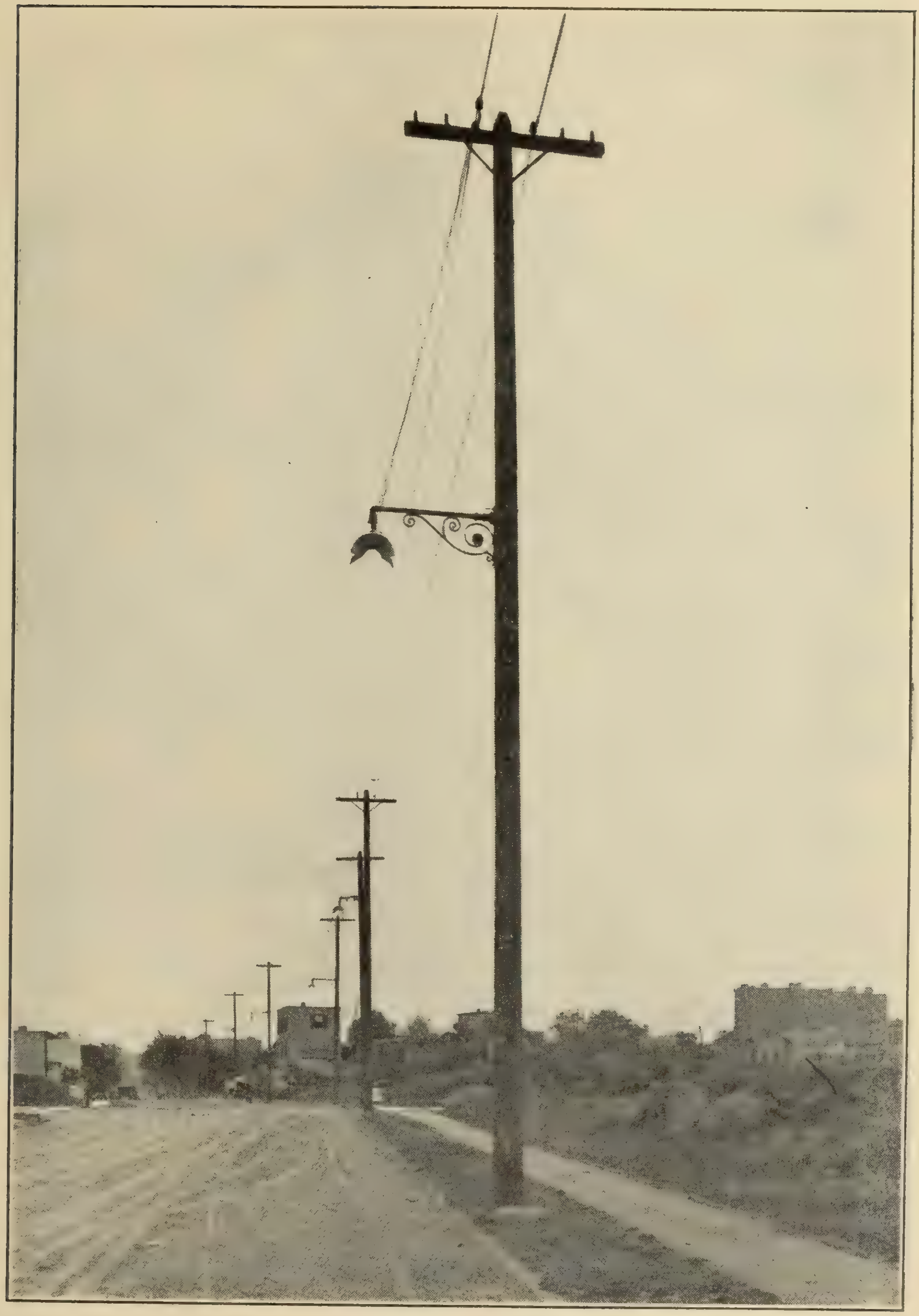


Fig. 15.

pleasing appearance possessed by almost anything that is clearly calculated to serve an evident purpose.

The applicability of this type of reflector to other illuminants

should also not be lost sight of. It can be applied also to mantle burners and to arc lamps, though probably the effectiveness of it in the case of these sources of light would not be so great as in the case of incandescent lamps.

There are also other fields of application outside of street lighting,—for example, long corridors such as the corridors of a hotel, could be very well lighted on this plan, and apart from the advantage of saving of electric current would be the additional advantage that the light would not shine through transom windows to disturb the sleepers in their rooms. The same advantage should be noted in the case of highway lighting. Many of us have experienced the inconvenience of having a bright light directly in front of the house, which shines in our windows at night. With the use of the Equilux reflector, this is prevented.

It is believed that the many obvious advantages of this type of reflector must appeal strongly to all who are interested in effective illumination and that a great increase in the economy and in the efficiency of illumination in particular fields to which this reflector applies, will be accomplished by its use.

A paper presented at a meeting of the New York Section of the Illuminating Engineering Society, New York, May 12, 1910.

ILLUMINATION TESTS.

BY CLAYTON H. SHARP AND PRESTON S. MILLAR.

The importance of illumination tests has been amply recognized in the TRANSACTIONS of the Illuminating Engineering Society and in the practice of illuminating engineers both in this country and abroad. Many of the tests which have been made have been valuable in advancing the art of illuminating engineering. Most illumination tests, however, have been made with some specific purpose in view, and hence have not included some of the elements without which a study of an illumination installation cannot be said to be complete.

It is the purpose of this paper to present the results of certain illumination measurements which have been made chiefly with three objects in view: first, to illustrate tests which can be made and methods which may be employed in the study of the illumination of an interior; secondly, to illustrate methods of discussion of results; and thirdly, to illustrate the degree of accuracy which it is practicable to attain in work carried out with ordinary field equipment.

Messrs. Little, Macdonald and McKay of the Electrical Testing Laboratories, very kindly volunteered their services in actually making these measurements, and the authors' thanks are due them for their courtesy and for the effectiveness with which the tests were carried out.

TEST CONDITIONS.

The tests were conducted in a room 12 ft. 7 in. (3.85 m.) long, 12 ft. 2 in. (3.71 m.) wide and 9 ft. 10 in. (3 m.) high. The ceiling was covered with white cloth. The walls were grayish-white, and the windows were covered with manila paper.

There were provided for the ceiling and walls black cloth coverings, which reflected practically no light and which could be removed readily. A screen was constructed by which the test-plate of the photometer could be shielded from all direct light from the light source, while a minimum of light from the ceiling

and walls was obscured. A second screen was of such shape and dimensions as to shield the plate from all direct light from the light source and from the ceiling, while obscuring a minimum of light from the walls. A third box-like screen was so designed that all light reflected from the walls directly could be screened from the test-plate, while a minimum of ceiling light was obstructed.

The light source consisted of a single 250-watt bowl-frosted, metallized-filament lamp, held at the watts necessary to produce its rated candle-power and equipped with a satin finish prismatic bowl reflector, mounted in a form-A holder. This unit was mounted upon a drop cord from a center outlet on the ceiling, the bottom edge of the reflector being 9 ft. 4 in. (2.84 m.) above the floor.

Fig. 1 shows the curve of the distribution of light about the lamp and reflector used in these tests. The values given are apparent candle-power as observed at a distance of 10 ft. (3.05 m.) from the light source.

Studies were made of the illumination on a horizontal plane 36 inches (0.91 m.) above the floor, (the "table plane") and on the ceiling and walls. The horizontal plane was divided into 25 rectangles of equal areas. A test station was located in the center of each such rectangle. In some of the tests upon the ceiling, corresponding test-station measurements were followed In other tests, stations were located in the centers of larger rectangles, both upon the ceiling and upon the walls. At each test-station, three to five settings were made by one observer.

Study of Illumination on Table Plane.

A series of tests of the horizontal illumination on the table plane was laid out with a view to determining by direct measurement, not only the total flux on that plane with the room in its normal condition, but also the proportion of such flux which was contributed by the light source directly, by the ceiling, and by the walls, respectively.

For example, with the walls and ceiling covered with black cloth, the illumination on the table plane was that due to the lamp alone (Test A) : with the walls black and the ceiling white, the illumination was due to the lamp directly and to the light of

the lamp reflected from the ceiling, (Test B): with the direct rays of the lamp screened from the test-plate, the illumination

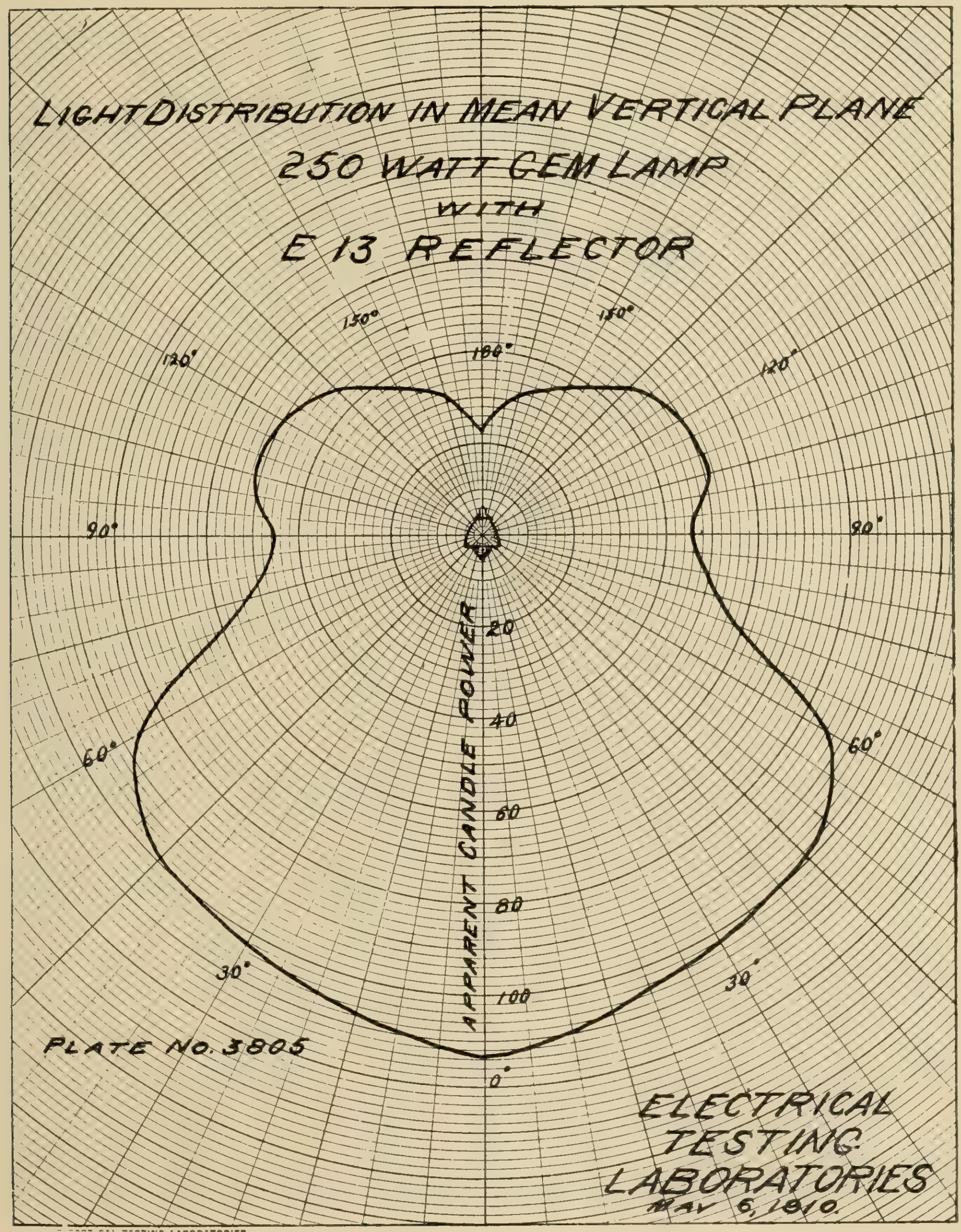


Fig. 1.

measured was that due to the light of the lamp reflected from the ceiling, plus the light of the lamp reflected from the

the walls, plus the light of the walls reflected from the ceiling, plus the light of the ceiling reflected from the walls (Test E).

In all tests, the light reflected from the brown linoleum-covered floor, from objects on the floor and from the wainscoting, below the 36-inch plane, has been ignored. The conditions under which the various tests were made are summarized in Table A.

TABLE A—CONDITIONS UNDER WHICH ILLUMINATION INTENSITY ON TABLE PLANE HAS BEEN MEASURED.

Test	Ceiling	Walls[1]	Light source	Light reaches photometer from
A........	Black[2]	Black	..	L
B........	..	Black	..	L + C
C........	Black	..	..	L W + WW
D........	..	..	..	L + C + W + CW + WC + WW
E........	..	..	Obs.[3]	C + W + CW + WC + WW
F........	..	Black	Obs.	C
G........	Black	..	Obs.	W WW
H........	..	Obs.	Obs.	C + CW
I........	..	Obs.	..	L + C + CW
J........	Obs.	..	Obs.	W WC + WW

Key—L = Light source.
C = Ceiling.
W = Walls.
CW = Wall light via ceiling.
WC = Ceiling light via walls.
WW = Wall light via other walls.

Note—Light source, ceiling and walls are considered to remain unmodified where not otherwise stated.

From the data obtained in these tests the composite light flux which produces the illumination on the reference plane can be analyzed and the value of each component perpendicular to the plane can be ascertained. Moreover the value of the components is in most cases not only known by direct measurement, but it can also be derived by adding or subtracting values obtained in other tests in which they are involved with other quantities By comparing such derived values with those obtained by direct measurement, a good check is obtained on the accuracy of the work and on the validity of the methods employed.

To get the luminous flux in lumens on the table plane under each of the above conditions, the average illumination intensity

[1] Down to line 36 inches above floor.
[2] Covered by non-reflecting black cloth.
[3] Photometer test-plate shielded from light by screens.

must be multiplied by the area of the plane, which was 153 sq. ft. (14.25 sq. m.). The average illumination intensity was found by averaging the values obtained at the 25 test-stations. This procedure was allowable, because these test-stations were situated at the centers of equal rectangles uniformly distributed over the plane.

TABLE B.—Determinations of Total Light Flux and Distribution of Light Flux Upon Plane of Reference.

Test-stations	Flux from— Light source (test A)	Flux from— Walls and ceiling (test E)	Sum (tests A + E)	Measurement of total flux (test D)	Variation—computed from measured value
1	0.78 ft.-c.	1.11 ft.-c.	1.89 ft.-c.	1.93 ft.-c.	—2.1%
2	1.08	1.23	2.31	2.35	—1.7
3	1.22	1.33	2.55	2.56	—0.4
4	1.03	1.27	2.30	2.24	+2.7
5	0.72	1.05	1.77	1.79	—1.1
6	1.05	1.30	2.35	2.26	+4.0
7	1.65	1.26	2.91	2.84	+2.5
8	1.98	1.30	3.28	3.28	0
9	1.51	1.27	2.78	2.90	—4.1
10	0.93	1.31	2.24	2.22	+0.9
11	1.15	1.19	2.34	2.30	+1.7
12	1.85	1.25	3.10	3.06	+1.3
13	2.33	1.20	3.53	3.64	—3.0
14	1.76	1.22	2.98	3.13	—4.8
15	1.07	1.21	2.28	2.31	—1.3
16	0.94	1.21	2.15	2.17	—0.9
17	1.43	1.22	2.65	2.74	—3.3
18	1.80	1.20	3.00	3.04	—1.3
19	1.49	1.24	2.73	2.63	+3.8
20	0.91	1.18	2.09	2.10	—0.5
21	0.72	1.03	1.75	1.80	—2.8
22	0.97	1.25	2.22	2.19	+1.4
23	1.13	1.21	2.34	2.23	+4.9
24	0.95	1.21	2.16	2.13	+1.4
25	0.68	1.11	1.79	1.76	+1.7
Avg. ft.-c.	1.25	1.21	2.46	2.46	±2.2%
Lumens	191	186	376	376	

Table B gives the detailed data on three of the above tests, showing how the illumination varied at different parts of the test-

plane and indicating how the illumination values at each test-station were obtained, not only by direct measurement, but also by derivation from values obtained in these tests. The degree of concordance of the various data is excellent and indicates the high accuracy attainable in work of this character.

In Table C is given a more complete set of such comparisons of derived values with values determined by direct measurement, the method of derivation being indicated, and also the percentage variations. For convenience, all results in this and later tables are expressed in lumens. The corresponding foot-candles or meter-candles may be computed in each case by dividing the stated lumens by the area of the surface in square feet or square meters, respectively.

TABLE C—ILLUMINATION ON TABLE PLANE.

Components	Measured		Derived		
	Test	Lumens	Tests	Lumens	Variation
Sum of all	D	376	A + E	378	+ 0.5%
			I + J	373	— 0.8
			A + H + J	380	+ 1.1
Due to light source alone	A	191	D — E	189	+ 1.0
			I — H	184	— 3.7
			B — F	184	— 3.7
Due to ceiling direct	F	42	B — A	35	—16.6
Due to ceiling indirect	..	..	H — F	26	..
(Walls via ceiling)			I — B	26	..
Ceiling total	H	68	E — J	66	— 3.0
Walls direct	G	86	C — A	80	— 7.0
Walls indirect	..	..	J — G	35	..
(Ceiling via walls)					
Walls total	J	121	E — H	119	— 1.6
			D — I	124	+ 2.5

In only one instance was the divergence between direct and derived values at all serious, namely, in the case of the flux from the ceiling. The value derived by subtracting the flux coming from the lamp directly from the flux from the lamp and the ceiling varies from the directly measured value by 16.6 per cent. This discrepancy does not appear very serious, however, when it is remembered that the derived value results from subtracting from each other two nearly equal larger quantities, so that an error of three per cent. in either of the larger values would ac-

count for the 16 per cent. variation in the smaller value. A similar consideration applies to the 7 per cent. difference in another test.

Finally, summarizing results given in Table C, we have the analysis of the illumination of the plane of reference as given in Table D.

TABLE D—ANALYSIS OF REFERENCE PLANE ILLUMINATION.

Component flux from	Derivation of value	Total lumens
Light source direct	Test A	191
Ceiling alone	Test F	42
Walls via ceiling	Tests H − F I − B	26
Walls alone[1]	Test G	86
Ceiling via walls	Tests J − G	35
Sum of all	Total Test D	380 376

A further study of the illumination on the test-plane can be made as follows:

Taking the average of all measured values of illumination at equal distances from the point immediately below the lamp, mean illumination curves were plotted showing the total illumination, the illumination due to the light source alone, the illumination due to the walls alone and the illumination due to the ceiling alone. These curves are shown in Fig. 2. In comparing point by point the measured total illumination intensity with the sum of the components, the differences were found to average less than 2 per cent., the maximum individual variation being 5.4 per cent.

STUDY OF ILLUMINATION OF CEILING AND WALLS.

In studying the illumination of ceiling and walls, photometric procedure was followed, which can be employed satisfactorily only with some form of illumination photometer of which the illuminated surface or test-plate may, when required, be located

[1] This value includes light reflected from wall to wall prior to being reflected from a wall to the plane of reference.

at a considerable distance from the photometer itself. The accuracy of the results obtained will depend of course in great

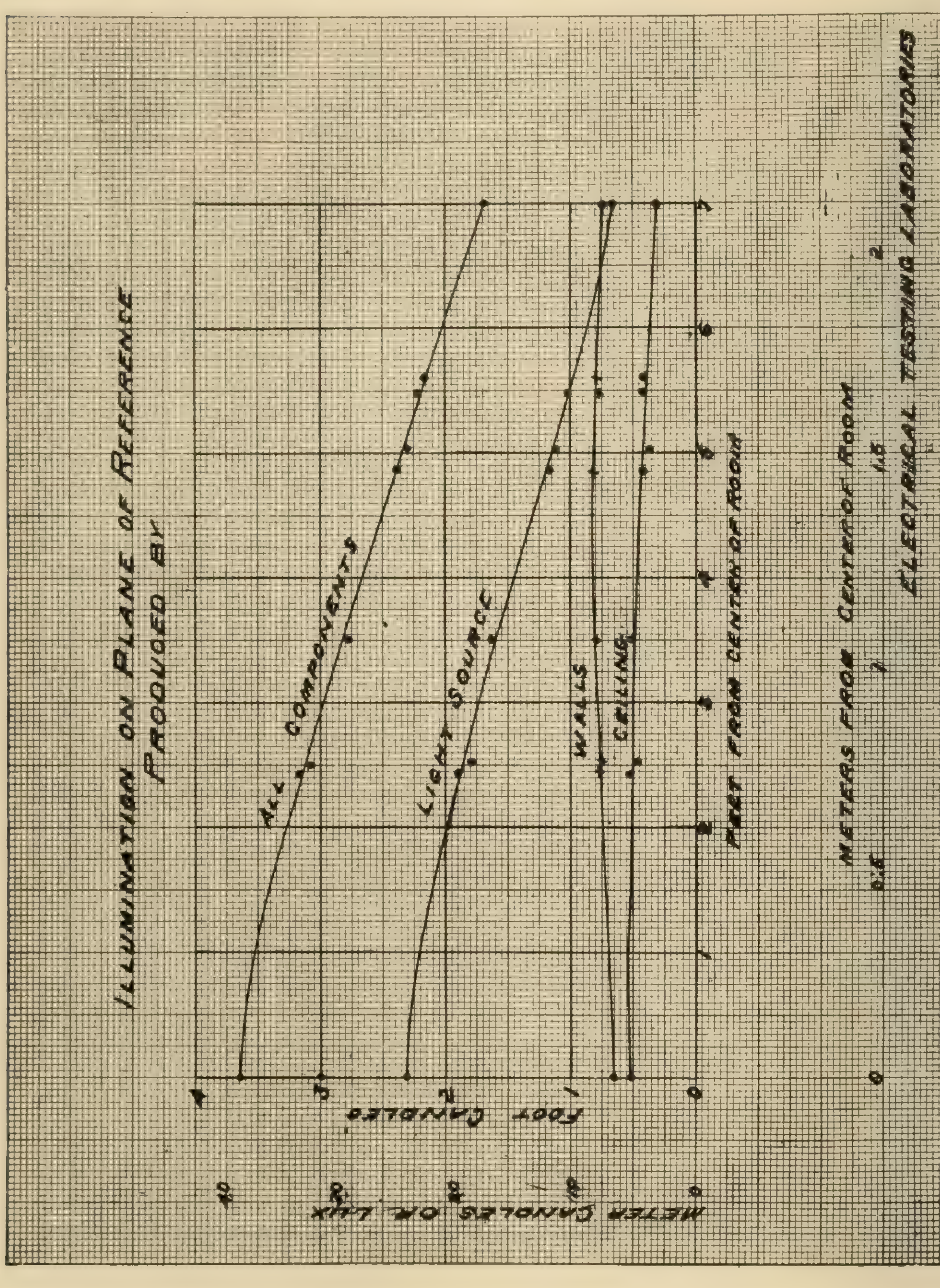


Fig. 2.

measure upon the precision capabilities of the photometer used, the extent to which the photometer complies with the theoretical requirements, and upon the skill and experience of the observer.

In the tests here described a detached test-plate was located

on the ceiling or wall in the position and at the angle desired. The photometer was removed from the test-plate a sufficient distance to minimize obstructions of light due either to the instrument or to the body of the observer. The test-plate in this instance consisted of a circular sheet of de-polished milk glass, 100 square inches in area (645 sq. cm.) with an opaque backing. This detached test-plate was viewed normally through the photometer in all cases. While not a perfect diffusing surface, it followed the cosine law with substantial accuracy through an angle of 60 degrees from the normal, and therefore served all practical purposes in these tests.

For a number of reasons it is not to be expected that this work with the detached test-plate will be as accurate as the work on the plane of reference previously considered, in which the test-plate was attached to the photometer. For one thing, the test-plate is more than 11 inches (27.9 cm.) in diameter, and in some cases the illumination on the area represented varies considerably, in consequence of which one portion of the photometric field would be brighter than another, and it would be necessary to integrate this according to best judgment in making photometric settings. Again, in some of the tests a smaller number of test-stations were used, in consequence of which the average value is not likely to be determined so accurately. In particular, in tests P and Q, the central test-station brings the test-plate very near to the light source in a region where the illumination changes rapidly from high to relatively low intensity. In this one instance the test-plate was not located in the center of the area to be represented, but was located within such area in accordance with best judgment, the variations in illumination throughout such area being considered. Slight variations in the illumination of this test-station would affect the result materially.

The conditions under which various tests were made employing the detached test-plate, are indicated in Table E.

Since time did not permit of as exhaustive a study of the illumination of the walls and ceiling as was made of the table plane, it is not practicable to analyze the flux as closely and accurately as was done in the other case. Certain analyses, however, may

be made, as indicated in Table F for the ceiling and Table G for the walls.

TABLE E—CONDITIONS UNDER WHICH ILLUMINATION INTENSITY ON CEILING AND WALLS HAS BEEN MEASURED.

Test	Light source	Ceiling	Walls	Test-plate on	Light reaches photometer from[1]
K ..	..	..	..	Ceiling	L W + WC + WW
P ...	..	Black	..	Ceiling	L + W + WW
Q ...	..	Black	Black	Ceiling	L
M ..	..	..	..	Walls	L + C + ¾W + WC + WW + CW
O ...	..	Black	..	Walls	L + ¾W + WW
R ...	..	Black	Black	Walls	L
S ...	..	..	Black	Walls	L + C

Note—Light source, ceiling and walls are considered to remain unmodified where not otherwise stated.

TABLE F—ANALYSIS OF CEILING ILLUMINATION. DATA REFER TO FLUX INCIDENT UPON ENTIRE CEILING AREA.

	Tests	Lumens	Lumens
Direct from light source	(Q)		183
Ceiling light reflected by walls back to ceiling	(K — P)	20	
Wall light reflected to ceiling	(P — Q)	77	
Total indirect light	(K — Q)		97
Total flux on ceiling			280

TABLE G—ANALYSIS OF WALL ILLUMINATION. DATA REFER TO FLUX INCIDENT UPON ENTIRE WALL AREA.

	Tests	Lumens	Lumens
Direct from light source	(R)		382
Ceiling—first reflection	(S — R)	116	
Walls—first reflection	(O — R)	104	
Ceiling via walls + walls via ceiling	(M + R) — (O + S)	70	
Total indirect flux on walls...			290
Total flux on walls			672

Note—Four walls are considered as a unit with respect to light incident and reflected.

Among the values determined for the illumination on the table plane, ceiling and walls, there is for each, the flux of light incident from the light source direct, all indirectly reflected

[1] For key see tabulation K.

light being eliminated. The sum of the values of such components upon each plane is comparable with the total flux of light produced by the light source, as computed from the curve of light distribution. Such a comparison is made in Table H.

TABLE H—TOTAL FLUX OF LIGHT FROM LIGHT SOURCE DIRECT. ALL INDIRECTLY REFLECTED LIGHT BEING ELIMINATED.

	Test	Lumens
Incident upon ceiling	Q	183
Incident upon walls	R	382
Incident upon reference plane	A	191
Total		756
Total flux computed from distribution curve (Fig. 1)		779

This check of the illumination tests shows accord within 3 per cent. It is an excellent demonstration of the validity of the methods employed, and of the substantial accuracy of the results.

Study of Ceiling as a Reflecting Surface.

From the data shown in Tables C, F and G, it is possible to compute the reflecting efficiency of the ceiling under the conditions which prevailed. Such a test appears in Table I, in which the total light reflected from the ceiling under various conditions is compared with the total light incident upon the ceiling.

It will be noted that 63 per cent. of all light falling upon the ceiling from the walls is reflected by the ceiling, while the corresponding value for the light incident upon the ceiling from the light source alone is 86 per cent. This difference is probably due to the fact that the ceiling receives the bulk of the light from the light source at angles of very high incidence, under which condition it would naturally display a most favorable reflection coefficient. Moreover, the cloth of which the ceiling was composed allowed less light to pass through its interstices at high angles; hence reflected a larger percentage.

A corresponding study of the walls as reflecting surfaces appears in Table J.

TABLE I—STUDY OF CEILING AS A REFLECTING SURFACE.

Flux	Tests	Lumens	Lumens	Reflecting effi. of ceiling
First reflections only, multiple reflections excluded				
Incident upon ceiling from light source	(Q)		183	
Reflected to table plane ..	(F)	42		
Reflected to walls	(S — R)	116		
Total flux reflected from ceiling			158	86%
Multiple reflections only, first reflections excluded.				
Incident upon ceiling from all sources except light source	(K — Q)		97	
Reflected to table plane	(H — F)			
	(I — B)	26		
Reflected to walls	(see note)	35		
Total flux reflected from ceiling			61	63%
All first and multiple reflections included.				
Incident upon ceiling—				
From lt. source	(Q)	183		
From walls	(K — Q)	97		
Total	(K)		280	
Reflected from ceiling to table plane—1st refl. from				
Light source alone ...	(F)	42		
Refl. of lt. from walls via ceiling	(H — F)			
	(I — B)	26		
Total	(H)	68		
Reflected from ceiling to walls— first refl. from				
Light source alone ...	(S — R)	116		
Refl. from walls via ceiling to walls ..	(see note)	35		
Total		151		
Total refl. from ceiling ..			219	78%

Note—See tab. G—Estimated as half the value (M + R) — (Q + S).

TABLE J—Study of Walls as Reflecting Surfaces.

Flux	Tests	Lumens	Lumens	Reflecting effi. of walls
First reflections only, multiple reflections excluded.				
Incident upon walls from light source	(R)		382	
Reflected to table plane ..	(G)	86		
Reflected to ceiling	(P — Q)	77		
Total flux reflected from walls			163	43%
Multiple reflections only, first reflection excluded.				
Incident upon walls	(See Tab. G)		290	
Reflected to table plane ..	(J — G)	35		
Reflected to ceiling	(K — Q)	20		
			55	19%
All first and multiple reflections included.				
Incident upon walls	(M)		672	
Reflected to table plane ..		121		
Reflected to ceiling		97		
Total flux reflected			218	32%

The low value for the percentage of light reflected by the walls on the test-plane and ceiling seems reasonable, if we remember that a very large proportion of the reflected flux travels from wall to wall and is finally absorbed. The components of this flux falling upon the test-plane and upon the ceiling, may reasonably be expected to be rather small; in fact, a simple comparison of the areas involved would indicate that the test-plane and ceiling would receive a smaller percentage of the light reflected from the walls than do the walls themselves.

Determination of Specific Intensity or Intrinsic Brilliancy.

In view of the great importance of this element in illumination installations, it was decided to make such determinations upon the walls and ceiling. Time did not permit of an exhaustive study, but the determinations were made for the ceiling when it received the total direct and indirect light flux, and again when

the walls were covered with black cloth; also for the walls when they received the total direct and indirect light flux.

The detached test-plate previously referred to was calibrated as a standard of specific intensity by producing upon it illumination of high intensity, determining the intensity, and determining the illumination which the detached test-plate produced under those conditions at a stated distance. For example, in the standardization test an illumination of 48.8 foot-candles was produced upon the test-plate, and it was found that under this condition the test-plate produced a normal illumination of 0.393 foot-candle at a distance of five feet (1.52 m.) along a line perpendicular to its surface. This yielded a specific intensity of 0.0982 c-p. per sq. in. for the test-plate as illuminated, which corresponds to a specific intensity of 0.002 c-p. per sq. in. per foot-candle of illumination. In determining the specific intensity of the ceiling or walls immediately after the illumination intensity had been measured by means of the detached test-plate, the test-plate was removed, while the photometer remained in position, and repeated observations yielded the specific intensity of the ceiling or walls as compared to that of the test-plate. Table K records some of the determinations made by this method.

TABLE K—SPECIFIC INTENSITY OR INTRINSIC BRILLIANCY OF CEILING AND WALLS.

Conditions	Test	Surface investig.	Specific intensity[1] Mean for entire surface	Minimum measured	Maximum measured
Nothing obscured	L	Ceiling	0.0032	0.0014	0.0097
Walls black	T	Ceiling	0.0016	0.0005	0.0061
Nothing obscured	N	Walls	0.0031	0.0023	0.0047

The value given for the mean specific intensity of the ceiling, 0.0032 candle per square inch, may be roughly checked by the use of the following equation: $F = \pi i$, where F is the average flux per square inch of the ceiling; or in other words, the total flux divided by the area of the ceiling in square inches, and i is the specific intensity required. The value so derived for the mean specific intensity will be larger than the value obtained by measurement, because it is based on the assumption that the surface of the ceiling is a perfectly diffusing surface, which it was not. The mean value for Test L, computed according to this equation, is 0.0040 candle per square inch.

[1] Expressed in c-p. per sq. in.

Precision of Setting.

Three to five settings were made at each test-station. The individual variation of each setting from the mean of the group of settings has been computed in all cases where the precision of settings was not influenced by the use of obscuration screens and where the attached test-plate was used. In all there were 530 such settings. The average individual variation of such settings from the mean of their group is 1.0 per cent. The greatest variations of individual settings from the means of their groups were —6.1 per cent. and +5.0 per cent.

Summary.

The tests and discussions presented in this paper include studies of the illumination on the table plane to show total light flux derived from the light source, ceiling and walls respectively; studies of the ceiling to show light flux from the light source and walls respectively; studies of the ceiling to show its reflecting efficiency; studies of the ceiling to show specific intensity; studies of the walls to show light flux from the light source alone and from the ceiling respectively; studies of the walls to show their reflecting efficiency and studies of the walls to show their specific intensity. The whole forms a very complete investigation of the illumination in this installation, incidentally illustrating methods of tests and affording opportunities to verify test results.

DISCUSSION.

G. T. Macbeth:—I believe that the particular kind of photometer or illuminometer used should be stated. This instrument is so valuable to our work that too much information cannot be given about it and the accessories which may be used to advantage with it. I would like to suggest further that the authors present a plan and elevation of the room showing the location of the test stations, position of the source, detail of the ceiling, and other information about the tests described where use was made of a detached test plate; also the methods and devices used when determining the illumination on the walls or ceiling, where it is not possible to place the screen of the illuminometer.

C. O. Bond:—The reflector which Dr. Sharp has described should constitute a step forward in the proper lighting of streets.

I notice that the twin parabolic reflectors are arranged in a horizontal plane 180 degrees from each other, which means that if they are mounted at the street curb line, the line of greatest illumination will be coincident with the curb. Would it not be well to place these reflectors, say, at about 165 degrees from each other, which would have the effect of giving better illumination in the center of the roadway. Furthermore, if the electric lamps used with the reflector were frosted on the under side there would be an increase in the light to be re-directed by the reflector and a decrease in the direct light near the bottom of the lamp post, thus to some extent avoiding "spot lighting."

Bassett Jones, Jr.:—The curve in Fig. 2 of Dr. Sharp's paper gives the illumination at 50 candle-power with the Equilux reflector at points 200 feet and 300 feet away. What would be the effect at these points with an enamel reflector? Another point is as to the maintenance of the polished surface. I do not know of any metallic surface that will stand exposure to the weather. My experience has been that the reflective surface wears off very rapidly, due not to the accumulation of dirt, but to the oxidizing effect of the acids in the air. Hence it seems to me that, in a reflector of this type, the efficiency of the device would fall off rather rapidly, in fact, so rapidly that it

would affect the value of the device very materially; at least its utility would be affected.

With any street lighting device of this type of which the units have to be set at long intervals, as on country roads which have very light traffic, if we use very large units as Dr. Sharp suggests with his 250-watt tungsten, a serious blinding effect will result. If the lighting fixture is placed up in the air, we will have very little in the summer months. There are very few roads that have practically no trees, the larger number of roads being very much overhung with them; hence the light would be mostly in the trees. Street lighting systems have been exceedingly deficient in their practical effect. I recall an installation placed upon a plane of 100 feet. In one particular system 80-watt series tungsten lamps were spaced about 200 feet apart and gave an excellent illumination. This system was a good illustration of efficient street lighting.

M. D. Jones:—It seems to me that, after all, it is the horizontal illumination that is important in street lighting. A lighting system is used to enable one to see to the best advantage. This brings up the question of glare, or the use of clear globes for street lighting. I believe it is unquestionable that in designing a street lighting system too much attention has been given to the question of illumination, without regard to the effect of it upon the eye.

H. E. Ives:—I want to express my appreciation of the practical way in which Dr. Sharp and Mr. Millar have treated this question of the walls and the ceilings. In a conversation which I had this afternoon, someone was bemoaning the fact that it was practically impossible, with coefficients of reflection, as given in tables for various kinds of paper, ceilings and so on, to calculate what the approximate illumination would be. It was brought out in this conversation that the coefficient of reflection for a wall paper, except in special cases, depends upon the operation of the device and the angle of reflection. Hence it is too much to expect that any figures could be given to calculate the illumination, due to the various elements of the surfaces of the room. It seems to me that the authors are deserving of commendation for presenting the problem in the best manner.

V. R. Lansingh:—In the paper presented by Dr. Sharp and Mr. Millar the authors have gone thoroughly into the subject but have left out one factor which it would have been well to include. This factor is the effect of the floor in increasing the illumination in the room. In the room where their tests were made, the floor was dark and probably had little effect, but in cases of a light floor, such as white mosaic, there may be a considerable increase in illumination.

In a paper in the TRANSACTIONS of the Society for October, 1908, by Mr. Rolph and myself, along similar lines to the one under discussion, we found that when both ceiling and floor are light, but the walls dark, these was but little increase in illumination due to the light floor. This is also true when the ceiling is dark and both the walls and floor light, but if, on the other hand, all three factors are light, we have a marked increase in illumination. This means, of course, that the effect of the floor in increasing the illumination of the room is due to the light from the floor being reflected to the ceiling and walls and then back again to the plane of illumination.

In the case where reflectors are used and a considerable portion of the flux is thrown to the floor we may have a very considerable increase in the total illumination. Thus, for example, when bare lamps were used with light floor, ceiling and walls, there was an increase of 16 per cent. in illumination on the test plane due to the light floor. When the same lamp was equipped with a reflector, the increase was 38 per cent. In the case of three bare lamps, the increase was 20 per cent. and when they were equipped with reflectors, the increase was 30 per cent. It is therefore evident that when we are dealing with light floor and walls and the ceiling of the room is fairly light, there may be a considerable increase in the useful illumination.

With regard to Dr. Sharp's paper on street lighting, I would like to emphasize what Mr. Jones has said with regard to the physiological effect of bright lights. Mr. A. J. Sweet of the Engineering Department of the Holophane Company has been conducting some experiments lately on the physiological effect of bright lights in the field of vision, and I would like briefly to give a summary of his results. The matter was presented in

detail about two months ago in a paper before the Franklin Institute. The method of test was as follows:

A given test plate was illuminated so that it could be seen easily by an observer at a given distance. A bright light was then placed directly in the field of vision and it was found necessary to increase the illumination on the test plate in order to be able to see as clearly as before. The increase in illumination was duly measured, the ratio between the two illuminations giving the net efficiency of the eye, or, in other words, the extent to which the ability to see had been lost by reason of the bright light in the field of vision. Thus, if it required

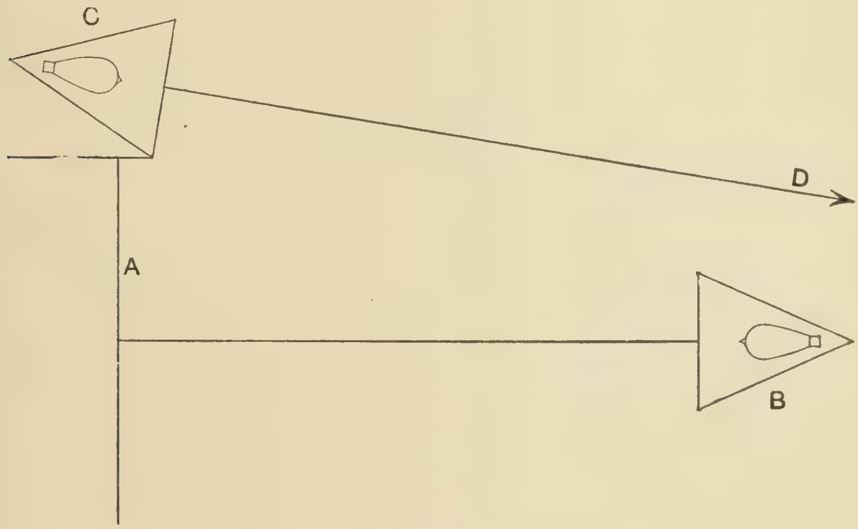


Fig. 1.

seven times as much illumination on the test plate to see as clearly after the light was in the line of vision as before, the visual efficiency would have been reduced to one-seventh of the former value.

Fig. 1 is a diagrammatic sketch showing the method of test. A test plate, covered either by lines at a slight angle or alternate squares and circles is pinned to a board marked *A*. This test plate is illuminated by an opaque reflector and lamp marked *B*. The lamp is placed in series with a rheostat, so that the illumination on the test plate *A* can be varied at will. Directly above the test plate, but so placed that no light whatever falls on it, is placed a concentrating reflector and lamp, which is also placed

in series with a rheostat, so that the amount of light can be varied at will. The observer is placed in line with the test plate *A* but at various distances. In the test actually conducted the distance varied from 20 to 60 feet.

The tests were conducted as follows: First the plate *A* was illuminated by the reflector *B* until the observer could distinguish certain squares or circles as adopted in ordinary work of this character; then the light *C* was turned on, and it was found necessary to increase the illumination on the plate *A* in order to distinguish the squares or circles as clearly as before. The increase in illumination on the plate *A* necessary to distinguish the squares or circles as well as before, can easily be found, as *B* can be calibrated so as to read the illumination on the plate *A* directly from voltmeter readings.

Briefly summarized, the results show that in the case of a 400 c-p. lamp, that is, when the amount of light shining in the eye is equivalent to 400 c-p., the efficiency of the eye has been decreased by 87 per cent., or in other words, it takes over seven times the amount of illumination to be able to see under these conditions as it would providing the light were not directly in the line of vision. Another point of interest is that even with a low intensity and a low candle-power in the field of vision, the efficiency of the eye drops off markedly. Thus with a reflector of about 50 sq. in. cross section and the candle-power reduced to about 12½, giving an intensity of one-fourth candle-power per square inch, we find that even with this low intensity, the eye has dropped in efficiency at least 30 per cent. This is contrary to the prevailing belief that with a low intrinsic brilliancy, the efficiency of the eye is not decreased even when the source of light is in the field of vision. It is thus apparent that in the case of street lighting the gain due to uniformity of illumination as shown by the illuminometer may be more then offset by the decrease in efficiency of the eye, so that the net visual efficiency, that is, the ability to see well, may be low.

The next part of Mr. Sweet's experiments was to gradually raise the reflector *C* upward so that it was taken out of the direct line of vision. The farther up it was raised the less was the effect of the glare. These results were plotted in a curve showing the increase in the efficiency of the eye as the light

was raised out of the field of vision. By referring to these curves it will be noted that at an angle of about 26 degrees the effect of the glare had disappeared, although both the lamp and reflector were clearly visible. Thus there seems to be a critical angle for practically all candle-power values and if the light is above this critical angle, which for most observers seems to be about 26 degrees, we find that the effect of the glare has vanished. Hence in practical work to get rid of the glare we must suppress the light between the horizontal and 26 degrees below. Inasmuch as the specifications of the National Electric Light Association call for the light from a street lamp to be measured at 10 degrees below the horizontal it would mean, if Mr. Sweet's tests are correct, that an entire revision of these specifications must be made, providing we wish to obtain visual efficiency rather than illumination efficiency as measured on the illuminometer. Inasmuch as the purpose of street lighting is to enable us to see clearly, it is evident that we must take into account both factors which make up visual efficiency, namely, the effect of distribution as measured by the illuminometer and the efficiency of the eye as shown by glare tests. A combination of these two should give us what may be termed "visual efficiency." It seems to me that Mr. Sweet has laid out a line of work which should be carried farther and that we should take into account in future street lighting both factors which go to make up the effect of visual efficiency.

Dr. Sharp's reflectors are extremely interesting and undoubtedly increase very largely the illumination as measured by the illuminometer on the surface of the street. It is interesting to note, however, that the idea in itself is old, although as far as I know this is the first actual reflector put on the market commercially. Something over four years ago the Holophane Company, experimented with a similar shaped parabolic reflector, except that the lower part of the parabola was not cut away, as it was not necessary on account of the light which shone through it.

M. D. Jones:—There is one point that I wish to discuss in connection with Mr. Lansingh's remarks. I know of a street in a certain New Jersey town that is lighted with rather dull incandescent lamps. They are series carbon lamps, not of the

best, and have a circular reflector, exceedingly dirty, so that the intrinsic brilliancy of the outfit is very low. I have been along that street a great many times and I have noticed that it was absolutely impossible to see vehicles that were driving in the opposite direction unless they had very bright carriage lamps or the usual automobile lamps. In walking along the streets in the same town my vision was arrested at this critical angle. I was not aware at the time that it was 26 degrees; in fact, I did not notice it, because, as one approached the lamp the brilliancy on the sidewalk, which is of ordinary flagging, was sufficient to offset largely the effect of getting under the lamp. When near the fixture, we began to get a low reflection from the sidewalk into the eyes—the same effect as a glare of light in the eyes. I do not think it is a matter so much of getting the downward rays from the lamp as it is of obtaining the generally soft illumination.

The light on the sidewalk was not particularly bright, but the surroundings were very dark, so that the intensity was sufficient to blind the eyes of anyone until practically under the lamp.

Prof. Shearer:—In the past attention has been given mainly to the problem of the economical production and distribution of light, and while these problems are by no means completely solved it is wise to take up the study of the eye in reference to the engineering proposition. The physiology of the receiver and the psychology of vision are important parts of the domain of illuminating engineering.

As an illustration I may mention that the beautiful uniform illumination so much praised in many cases may prove very trying to the eye. Dr. Northrup and I missed a train at the new Union Station in Washington recently and waited in the large waiting room for two hours. We both noticed that the eye became restless and fatigued.

No doubt the eye has been developed with reference to natural environment, and the devices for protection of the retina from extreme light are evidences that this receiver is extremely delicate. That this sensitive mechanism, of whose real working we know so little, needs constant opportunity for recovery after strong excitation by the reception of weaker illumination or the variation of color, admits of no discussion. It follows

that an eye forced to receive uniform illumination for any considerable period would be tortured much worse than by occasional glare relieved by dim areas.

I hope that more information as to the actual behavior of the eye under various conditions may be obtained. The very interesting experiments described by the President to-night are in the right direction. Care should be taken to eliminate the errors due to expectation and retinal fatigue. By the discus-

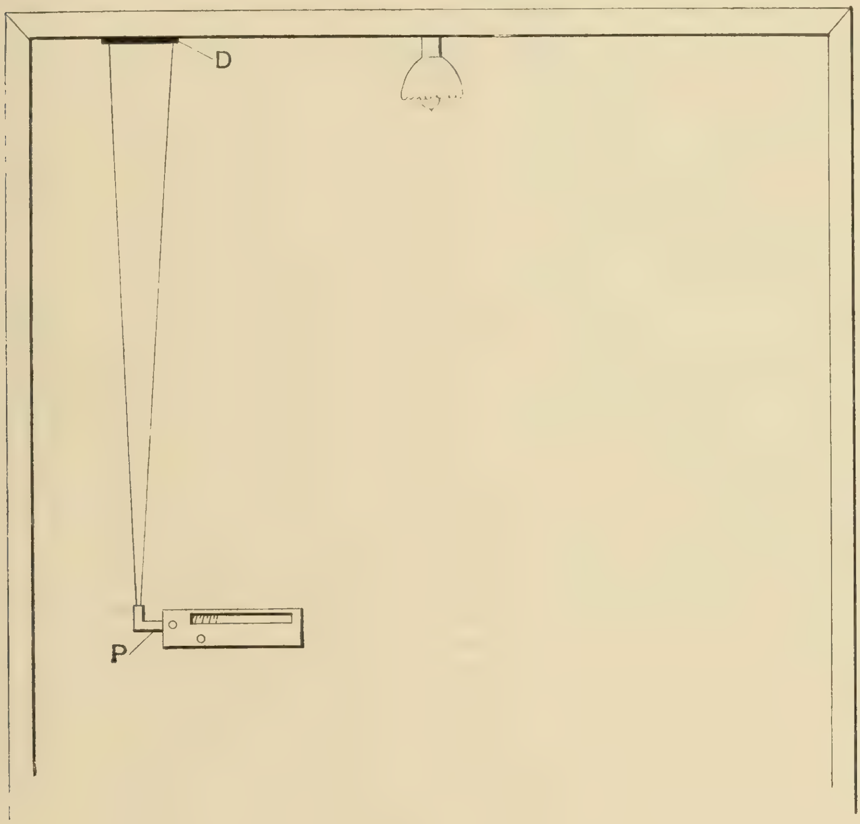


Fig. 3.

sion of such matters in addition to the study of economy in the dollar sense your society may be of great public benefit.

Clayton H. Sharp and P. S. Millar (communicated after adjournment):—One of the speakers requested that information be included in the TRANSACTIONS regarding the details of the room and lighting installation, and details of the methods and devices used in making the tests. Complete information as to the room and installation may be found under "Test Conditions"

in the paper. The devices and methods used in making the various tests may be best described by illustration.

Fig. 3 illustrates the use of the detached test plate, by means of which the ceiling and wall illuminations were studied. The plate D was located at the point where the intensity of the illumination was to be measured. With all intervening screens removed, the surface of the distant illuminated test plate is seen

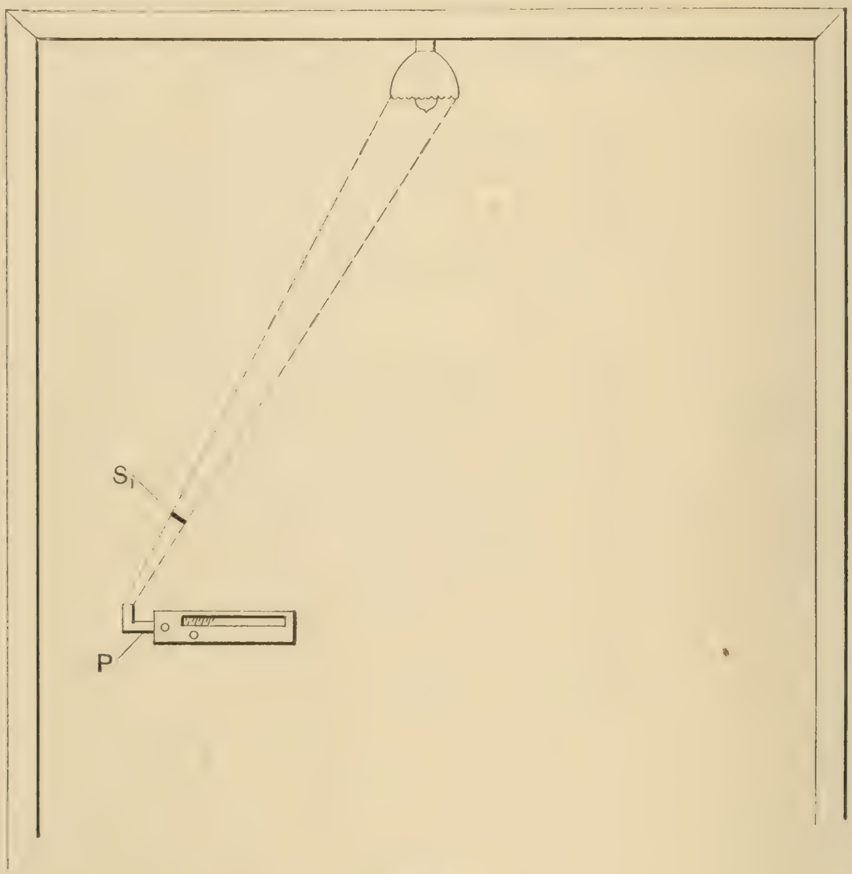


Fig. 4.

in the field of the observing tube in juxtaposition to the standard photometric surface. Since the apparent brightness of the plate is independent of its distance from the photometer, the distance of the plate makes no difference, provided that the plate is large enough to cover the field of the photometer prisms.

Tests E, F, G, H and J were made while no direct light from the light source was permitted to fall upon the photometer

test plate. Fig. 4 illustrates the disposition of apparatus for such tests. The screen S_1 was black and opaque. It was held in position directly between the lamp and the test plate at some suitable distance from the latter, in order that it might obstruct direct light from the lamp, while obstructing a minimum of light from the ceiling or walls. It was found that under conditions of such uniform illumination as prevailed in this test installation, the distance between the screen and the photometer test

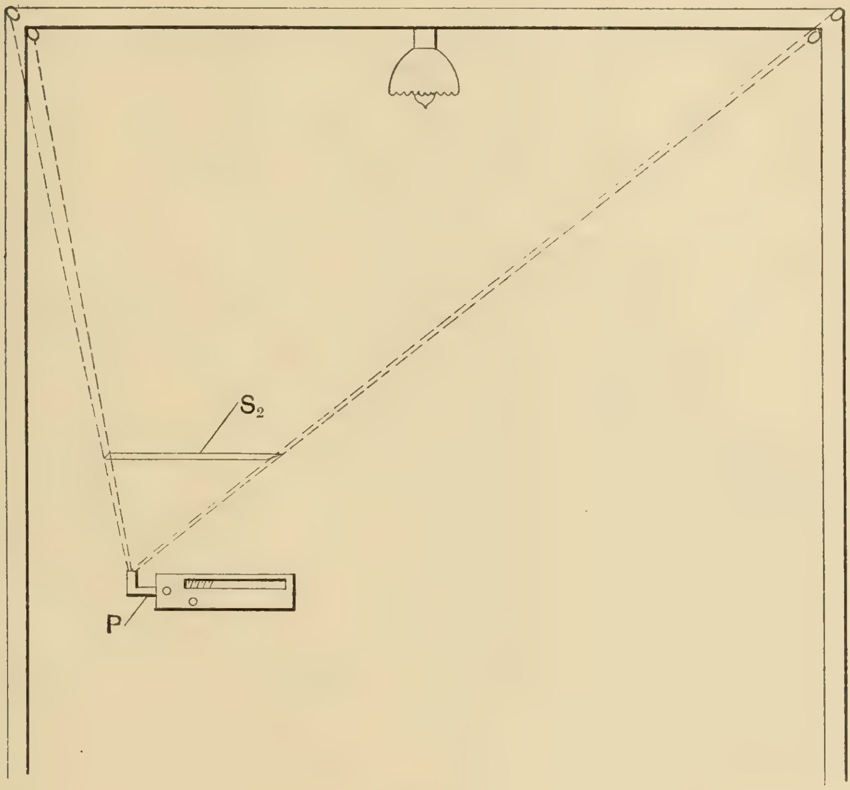


Fig. 5.

plate could be varied considerably without altering the results materially.

In test J it was desired to obstruct all direct light from the light source and ceiling, permitting only the light from the walls to fall upon the photometer test plate. To accomplish this, screen S_2, Fig. 5, was constructed. This consisted of black cardboard of length and breadth proportional to the length and breadth of the ceiling. It was so located above the photometer test plate at each test station as to accomplish the desired ob-

ject. To facilitate the location of this screen a small pilot lamp was placed at each corner of the ceiling. When the test light source was not operating and these small lamps were lighted, the location of the screen became a comparatively simple matter when judged by the four shadows which the screen produced upon the test plate.

In tests H and I it was desired to obstruct all direct light from the walls, permitting only light from the ceiling or from

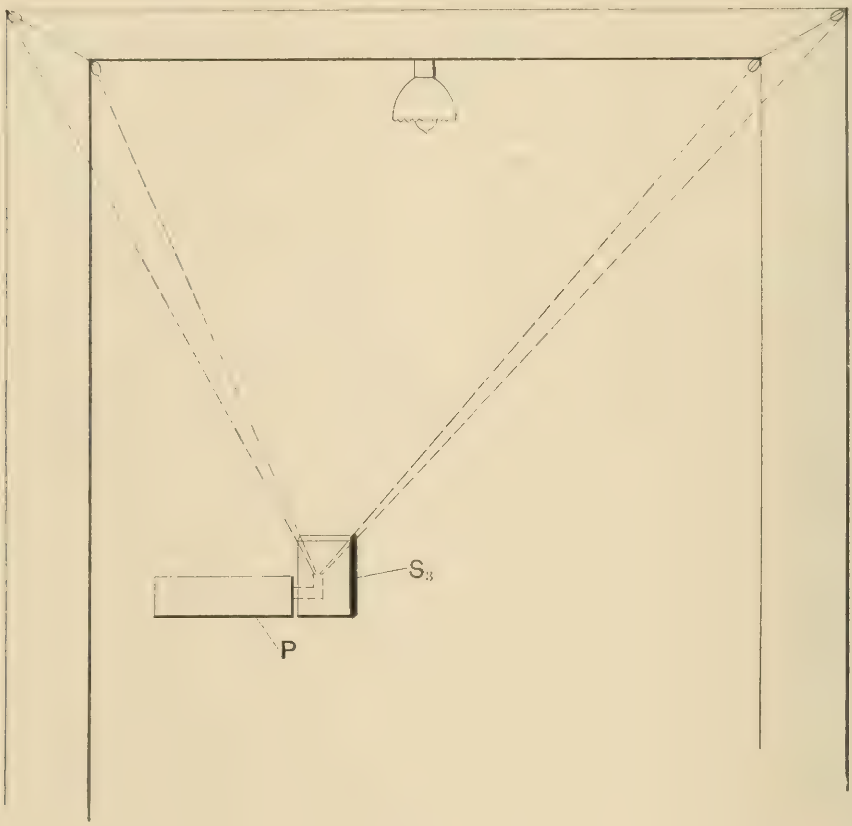


Fig. 6.

the light source or from both to fall upon the photometer test plate. The means of accomplishing this are illustrated in Fig. 6. The box-like screen S_3 has dimensions proportional to those of the room. It was mounted independent of the photometer, and by means of the pilot lamps previously referred to, was adjusted vertically and horizontally until it accomplished the desired purpose of screening the photometer from all light coming from the walls. The photometer used was a Sharp and Millar instrument.

Clayton H. Sharp:—In regard to illuminating the center of the road. Of course the two sides of this reflector could be placed at a slight angle to each other and that would help where all the lamps are on one side of the street. Where the lamps are on both sides of the street the present arrangement would be better. It would also be better where the street is quite narrow; where the lamps are placed fairly well toward the center of the street; and where they are suspended from the center of the street. In any device of this kind it is impracticable to meet exactly all conditions, and any design must be, therefore, to a certain extent, a compromise design. I think likely that the 180 degree arrangement would satisfy the greatest number of cases, although, of course, the slight modification which Mr. Bond suggests can readily be carried out.

The tip or "bowl" frosted lamp might be used with good effect. If the lamp is entirely frosted, the increased illumination at a distance with this reflector is not marked, for this reason: when we take a theoretical parabolic reflector and plane the source of light at the focus of that reflector, we see the entire surface of the reflector, if we are looking along the axis, apparently covered over with an illuminating surface which has the same specific intensity as the source which is placed in the focus. That is to say, if we place a tungsten filament at the focus, and if we look at the surface of the reflector, it is as if the entire surface were covered over with tungsten filaments. That is why we get such a great intensity in the beam of a searchlight, where the crater of the arc is at the focus.

However, the specific intensity or the candle-power per square inch of the surface of the reflector is not greater than that of the source itself. It must be a little less. So that with this reflector, if it were used in connection with a frosted bulb lamp, we get an apparent specific intensity on the surface which is the same as that of the frosted bulb, and that is not very great. There is no glare from it and there is also no very great increase in the illumination produced by the projected beam. The beam is diffuse and it does not amount to anything comparable to that produced by the clear lamps.

With the clear lamp we have a specific intensity corresponding to the filament itself, no greater, rather less, so that we

have worse conditions as regards glare. However, going to a distance from the lamp, such that the eye comes within the 26 degree angle, the distance from the lamp is so great that the glare does not interfere very much with our seeing things. When, however, we come up nearer the lamp, we get outside of the glare produced by the reflector, and have the glare from the lamp alone, as we should have it with any type of reflector we use.

Mr. Jones has outlined some of the conditions of street lighting which, in many practical cases, we must regard as ideal. No doubt it is a very great advantage in street lighting to cut down the specific intensity of the sources of light, and put them so close together that fairly uniform illumination is obtained. Then we have something that is good. But we could do very little street lighting if we should attempt to carry it out altogether on these lines. As a practical question, we must economize the light which we produce and utilize it as well as we can: but then it would seem almost impossible to avoid glaring lights.

As Mr. Jones has said, if we place the lamps so that they no longer come within direct range of vision, they are quite likely to come above the branches of the trees, illuminating the trees instead of the roadway.

In Mr. Sweet's experiments, as I understand it there was about 85 per cent. diminution in the sensibility of the eye; the eye was looking at a 300 or 400 candle-power adjacent to the observed object and at the same distance. In that instance the glare must have been intense. Of course it decreased the visibility accordingly.

At the other extreme we find the condition pointed out by Mr. Jones, where the reflected light from the sidewalk, feebly illuminated by an old carbon lamp up on a pole, decreased the visibility of other objects. We have come to the point, in short, where we must either put up with a diminished sensibility of the eye, or have no illumination. In the latter case the eye will have a wonderful sensibility, but it will not see anything.

Of course the brilliancy of a polished metal surface will decrease in time. The first one of these reflectors made for me is about two years old. It is of polished zinc. At present it

is coated with a thin layer of oxide but the polish seems to remain intact underneath and the reflector is still efficient. Granted, however, that the polish will decrease in time, we have to offset the greater cost of maintenance of the polished reflector against the lower efficiency of the enameled type; or putting it in another way, we have to compare the cost of taking that reflector down, perhaps once a year, and cleaning it and repolishing it, with the cost of trimming an arc lamp fifty-two times a year. It is quite clear that this cost would be considerably less.

A paper presented at a meeting of the Philadelphia Section of the Illuminating Engineering Society, Philadelphia, Pa., May [illegible].

COLOR VALUES OF LIGHT FROM ELECTRIC LAMPS.

BY G. H. STICKNEY.

It goes without saying that the color of artificial light should approximate the color of the natural daylight. How close this approximation must be depends upon the use to which the light is to be put. Moreover, it does not always follow that an actual daylight color of light is most advantageous for all purposes. In fact a slightly tinted light is often preferable. The features controlling the degree and quality of color in light are ability to see, pleasure and comfort in seeing, and color matching or selection.

In order that we may arrange our thoughts for the consideration of color problems let us discuss briefly:

1. The physical, physiological and psychological aspects of light.
2. The lighting characteristics of the various lamps available.
3. Requirements of lighting problems and general applications.

Light.—Light, as we all know, is a form of wave energy. Light waves differ fundamentally from heat, sound, and other waves merely in regard to frequency and wave length. We ordinarily recognize as light those wave lengths which stimulate the eye, causing sight. These different wave lengths produce the simple colors of light, corresponding to the production of different pitch in sound. Visible light waves represent a little less than an octave from the red at a vibration of about 420,000,000,000,000 per second to the violet at about 750,000,000,000,000.

Unlike sound waves, light waves are seldom produced as simple vibrations but rather as complex vibrations. A beam of light is usually composed of a number of different wave lengths. The so-called "simple" white light is the most complex of them all, being composed of all the different wave lengths throughout the visible range in a specific combination.

Daylight being the predominating light gives us our concep-

tion of white light and makes it seem common and simple. Since daylight is emitted by the sun and filtered by the earth's atmosphere it is not an absolute fixed standard as to color, but varies through a certain range on account of the varying absorption of our atmosphere. This variation is produced both by the degree of moisture in the air and also by the angle at which the light penetrates. The short waves being most affected by the atmosphere are deflected and give the effect of blue sky, while the direct sunlight appears of a yellowish tint. These two combined and diffused together form average daylight.

The light from practically all artificial sources is tinted in color, due to a deficiency or excess of certain wave lengths, depending upon the method of production. Artificial light is produced from vibrating material either by temperature radiation or luminescence. When we raise the temperature of a solid body it first begins to glow a dull red, then passes through the yellow stage to the so-called white heat, as the shorter waves are added by the increased temperature. With the increased temperature comes increased efficiency. Unfortunately no materials have been discovered which are refractory enough to withstand the temperature corresponding to white light. Even carbon operated at its vaporizing temperature gives a slightly yellow tinted light.

Luminescence is applied to the production of light by other means than the direct temperature effect. Fluorescence and phosphorescence are forms of luminescence, but they do not at present play an important part in practical illumination. The flaming arcs and other forms of vapor arcs are the principal practical examples. With these lamps the color of the light and the efficiency become functions of the material rather than the temperature at which they are operated.

So far we have discussed the color of light objectively in terms of its original production. The color of a beam of light may be modified by the surface upon which it falls or the medium through which it is transmitted. This phenomenon may be produced by:

1. Absorption, as in ordinary surfaces and media.

2. Diffraction, and interference as in thin plates, insects wings, oil on water, or diffraction gratings.

3. Refraction, as in the prism.

Absorption plays the most important part in practical illumination, while diffraction and reflection are particularly interesting for scientific investigation.

Most of the color modification as in colored objects, colored glass, etc., are due to the selective absorption. We say that an object is red because it reflects red light and absorbs the complementary color. It can appear red only when light falling upon it contains the wave lengths to which it responds. If the light is deficient in red the object is dulled or may even appear black. For example, when the beam from an arc projector is directed on a white screen, since the light of the arc approximates daylight in color the screen appears white.

If we insert colored slides in the lantern the screen apparently assumes colors corresponding to the colors of the slides. We hold a yellow fabric before the screen and it appears yellow in contrast to the white background. We insert a yellow slide and note that both the screen and the fabric become yellow, nearly blending in color. A similar effect will be observed by viewing a yellow and white plaid under a yellow light; corresponding effects are obtained with other colors, the degree depending upon the purity and correspondence of the colors. Again with the white beam we examine a blue fabric against the screen. It shows up rich and brilliant. We pass series of yellow slides of various shades through the lantern and blue fabric is radically changed. In all cases it is dulled and in one case appears nearly black. Here again the phenomenon is not peculiar to yellow light alone, but will occur whenever an object is viewed in a light of complementary color.

Most absorption colors are complex and contain more than one wave length. This is illustrated by projecting the spectrum upon the screen, whereby the pure colors are arranged in order of their wave length from red to violet by virtue of the dispersive effect of the prism which diverts the short waves more than the long ones. By passing the yellow slides before the beam of light we find that the yellow beam may be produced by absorbing all but the yellow light, or by absorbing all but the orange and green, or by absorbing merely the blue. All this brings us to the physiological aspect.

We see by the projection of an image upon the retina of the eye whereby certain nerve centers are stimulated and the impression perceived.

We have referred to the limitation of the range of visible wave lengths. Now there are shorter waves than the violet and longer waves than the red, but they are not visible because the eye is not able to discern them. The short waves of the ultra violet are evidenced by their chemical action, while the long waves of the infra-red are shown by their heat effects. The former are sometimes referred to as chemical rays and the latter as heat rays.

As we have noted, the eye is unable to analyze a light beam into the component parts, or even to distinguish between simple and complex colors This is due to the construction of the eye, which, unlike the ear, is not provided with a receiving element corresponding to each wave length. The color sense in the eye consists of only three divisions corresponding to red, green, and violet; and all color sensation depends upon the proportion in which these are excited. Moreover, the eye has no fixed standard of color, and many conditions effect the color judgment. For example, if we spend several hours in a yellow tinted light the light apparently becomes white, and, in contrast to it, daylight for a time seems blue. Again, if we place two colored objects side by side we obtain an effect called "simultaneous contrast," which causes one or both colors to appear of different color than they would if viewed separately. Again if we look with concentration at a particular color, especially if it is brilliant, the eye may become fatigued to that color so that it appears duller or blurred. On looking away an after-image of the complementary color is likely to be seen.

Another feature of color vision which is often interesting is the observed difference in the sensitiveness of the eye at high and low intensity. At very low intensity the eye is apparently more sensitive to blue and green lights, while at high intensity it is more sensitive to yellow light. This is, however, to some degree counteracted where light is projected to some distance or through fog and smoke by the superior penetrating power of the yellow light.

All people do not see colors equally well. A surprisingly large

percentage are color-blind; that is, their eyes are partly or wholly deficient in one or more of these color senses. This may be caused by ill-health, or by over exposure to an excessively tinted light. In many cases partially color-blind people are unaware of the defect or are thought by their friends simply to have an eccentric color taste. What they see corresponds to what a normal sighted person sees under a light deficient in the corresponding color. Eyes exposed to excessive intensity of light are differently affected by colors at opposite ends of the spectrum. With red light a burning effect is immediately felt but is not likely to last long. Excessive exposure to violet or ultra violet produces an effect which often does not develop for a considerable time and may last for a long period or become permanent. It is, therefore, exceedingly dangerous. Fortunately the light of none of the common illuminants has an excess of violet. In general it may be concluded that light approximating natural daylight quality is safest and best suited to the eye.

In producing artificial illumination it should be remembered that beyond the question of seeing with ease and comfort it is highly desirable that the light should contribute to the pleasure of seeing. In regard to this feature the color of light has an influence in connection with mental suggestion. No other light would give more pleasure in seeing out of doors than we obtain from bright daylight. A tinted light would make the day seem dull and gloomy, but in contrast to daylight a yellow tinted light indoors produces a pleasant sense of warmth and relaxation, while a blue or green tinted light produces a cold, disagreeable effect.

The choice in color of light is to a degree dependent on previous experience of the users. This is often evidenced in the sales force of a large store. The speaker has frequently observed difference in the demand of different cities or different stores for the handling of the same kind of merchandise. As a rule, salesmen who have always sold either unit white or yellow light will resist a change.

The spectroscope and the spectrophotometer serve for the study and measurement of color light. The Ives colorimeter is a useful instrument for color measurement. Being based on the three-color principle it permits a simple and less laborious

method for many classes of color measurement than the spectrophotometer. The lumichromoscope and color booths devised by Mr. W. D'A. Ryan have been used to some extent to show the effect of colored lights on various fabrics or colored objects. These instruments are especially useful for practical demonstration.

It is evident that the most exacting color requirements is presented when the light is to be used for color matching or selection. The rigidity of this demand depends on the kind or grade of material as well as the process involved.

For store lighting the practice is to provide a light slightly warmer or more yellow in tone than daylight as a compromise between daylight and evening conditions. While this may not ensure accuracy in selecting the most delicate shades it is sufficiently accurate for ordinary requirements and, furthermore, provides a pleasing general effect in the store.

For the most accurate color matching in textile mills there is a demand for a light approaching the north sky effect, which is bluer than average daylight

Two essentials of accurate color matching which are frequently overlooked are intensity and diffusion of light. Many failures to match under artificial illumination have been due in part to lack of intensity and proper diffusion. If we consider the question at all from this standpoint it becomes perfectly evident that we cannot see color as accurately with a low intensity of light as with a high intensity. In general practice stores are not provided with enough artificial light to compare favorably with day illumination. While the effect of diffusion is not so readily evident, anyone who has observed the effect upon a delicate fabric of glaring, flat and diffused illumination will readily concede the importance of the diffused illumination.

Let us consider briefly the color characteristics of some of the principal electric lighting units available. The lamp most commonly used for the most accurate color matching is the carbon arc. In discussing the color of the light from arc lamps, it is essential to differentiate between the various types of lamps as there is considerable difference between them. The light of the carbon arc is composite, being produced partly from the glowing electrodes and partly from the arc stream. The electrode light

is slightly yellow in tone while the arc stream is bluish. The open arc, while it gives an excellent quality of light, has been generally superseded in this country by the enclosed arc, which produces a steadier light, is cleaner and more easily maintained. Of the enclosed arc lamps the high-ampere direct-current lamp operated with 80 volts at the arc gives the best results. Contrary to ordinary belief the light of this lamp, particularly when equipped with opalescent globes, is perceptibly warmer or more yellow in tone than daylight as the crater light predominates over that of the arc stream. For good results it is essential that the lights from crater and arc be thoroughly mixed and diffused. This is one of the important functions of the arc lamp diffuser. The light of the intensified arc is very slightly warmer in color than the ordinary enclosed arc since the small diameter of the carbons makes the crater light still more intense. On the other hand, with an enclosed arc operated with 160 volts at the arc or with low current (say four amperes or less) or on alternating current, the arc stream light becomes more predominant and produces a slight purplish tinge, which renders the light perceptibly less satisfactory.

For color-work in dry goods stores and for viewing paintings in art galleries the most accurate results have been obtained from the 6.5-ampere direct-current enclosed arc lamps equipped with diffusers or from 6-ampere direct-current intensified arc lamps. In stores where the provision of a color matching intensity throughout would make the cost excessive, it is well to use color rooms or booths, wherein either white or yellow tinted light can be provided at will to simulate day or evening conditions.

In one of the leading button factories where exacting color selection was required for the shading, sorting and inspecting of buttons, satisfactory illumination was provided by means of 6.5-ampere direct-current enclosed arc lamps with inverted diffusers and opalescent outer and inner globes. The work was done on tables 10 ft. long by 4.5 ft. wide. Two lamps were hung about 4.5 ft. above each table. In this process buttons of a single design were sorted into as high as 17 different shades where an ordinary observer would readily detect only five or six even under daylight.

For color matching in textile mills, where the north sky effect is required, the English practice has been to use high-

current open arc lamps with blue glass globes. In this country the direct-current enclosed arc designed for currents as high as 16 amperes has been used. It has recently been found practicable to better these results by providing a special reflector with a particular shade of blue diffusing glass. Very good color has been obtained by means of carbon-dioxide vapor arc. While this gives a banded spectrum and is at present rather expensive, it is an interesting and promising development. The nitrogen vapor arc gives a yellowish or pinkish light. The direct-current magnetite arc gives a very close approximation of bluish white light. It has not as far as I know been tried out for careful color matching.

The ordinary flame arc lamp is, of course, too yellow for this purpose, but there is a white flame electrode which apparently approaches white light. These electrodes have apparently not been tried to any extent for careful color work.

The ordinary mercury arc, of course, shows the extreme case of color distortion and is never recommended for lighting where color is important.

All the lamps of the incandescent series produce a yellow tinted light approaching white in the order of the practical operating temperature of their filaments, namely, carbon, metallized carbon, tantalum and tungsten. The color of the light is warm and particularly pleasing and for the uses to which they are generally put are superior to white light.

The Nernst glower gives a light of about the same color as the tantalum lamp, the radiation being slightly selective or luminescent.

The light of the tungsten lamp comes near enough to daylight for general store lighting and ordinary color selection. Its variation is in the direction which gives the most pleasing effect. The color value of the tungsten lamp has recently been demonstrated by its selection for the illumination of painting galleries by several of the principal art museums of the country.

No one type of lamp provides a color of light suitable for all conditions. In many cases the exact color is not the determining factor. Any lamp approximating daylight, especially if the color be pleasing, is suitable. Where color is important an electric lamp can undoubtedly be selected which will meet the requirements.

A paper presented at a meeting of the Philadelphia Section of the Illuminating Engineering Society, Philadelphia, Pa., May 20, 1910.

INCANDESCENT GAS LIGHTING

BY M. C. WHITAKER.

This paper is presented for the purpose of reviewing some of the progress and development in incandescent gas lighting during the last year or two. The subjects naturally divide themselves under several headings which are rather disconnected.

Fixtures.—The gas lighting industry has its greatest trouble with the fixture and appliance problem. While it is true that buildings and houses supplied with gas are often equipped with fixtures put up under contracts these contract fixtures are frequently disapproved by gas men. The minimum price reported is $6.05 for fitting up the entire house with gas fixtures, and it can hardly be expected that there will be any artistic effect or structural value in fixtures at that price. In many of the buildings operations the owner is a contractor, or an operation engineer, and his interest is simply in building the house and selling it. Artistic and well constructed gas fixtures do not concern him and do not concern the prospective buyer until it is too late. In the last year or two, however, a great deal has been done to improve gas fixtures. The accompanying cuts will show the trend of this development.

There is a well established movement on the part of gas fixture houses to give gas fixtures, and appliances that will meet any exacting conditions that the architect or illuminating engineer may choose to impose.

Gas Ignition.—The developments of the last year or two show considerable progress in convenient gas ignition, and while they do not present anything which is radically new, they embody modifications eliminating defects of the older systems.

The principle of igniting gas by producing a kindling temperature in or near the burner, by means of a wire or filament which has been heated to incandescence by an electric current, is not new. It is also an old and well-established fact that a

mixture of illuminating gas and air under certain conditions produces, by means of what is known as catalytic action, a "boost-

Fig. 1.

ing" influence on the temperature of a platinum alloy filament. The heating of the filament by electricity is easy to control, but

the "boosting" action of the gas is very difficult to control so as to prevent melting the filament.

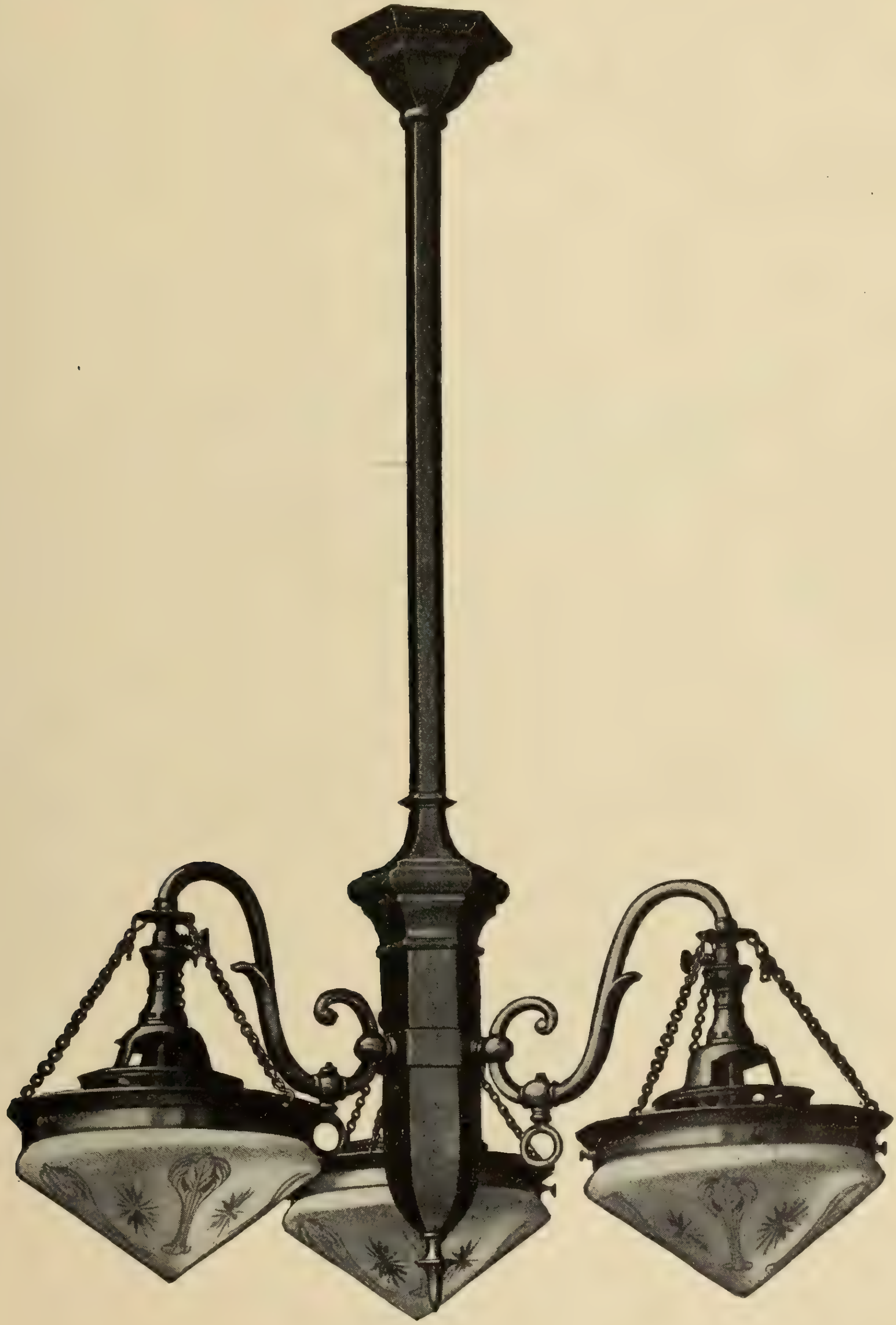


Fig. 2.

The success of this igniter is dependent upon the utilization of

the two principles referred to; namely, the initial heating of the filament by an electric current and the final "boosting" of the

Fig. 3.

filament temperature by the catalytic action of the gas, up to the kindling point of the mixture. The relation between the resis-

tance of the filament and the energy of a dry cell of special design was worked out so as to produce temperature in the filament high enough to induce the catalytic action. For the purpose of illustration (see Fig. 4), we will say that this temperature is approximately 500 to 600° Cent. The igniter is then designed so that the amount of gas and air mixture admitted to the filament is limited—being determined by the amount required to boost the temperature of the filament, by the catalytic action mentioned, to the kindling point of the mixture flowing from the burner nozzle. For the purpose of illustration, we will say that this kindling temperature is 1500 to 1600° Cent. The filament has a melting temperature of approximately 2000° Cent. It is obvious, therefore, that the igniter construction must be such as to limit the catalytic action and keep the temperature within the 2000°

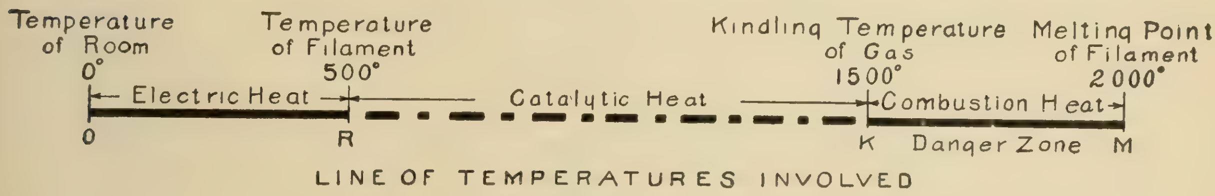


Fig. 4.

maximum. Furthermore, as soon as the ignition takes place, the stray currents of active mixture must be automatically swept out or exploded in order to relieve the filament of any further danger.

The problem was approached on those lines, with the result that a single dry battery cell was found sufficient to produce the initial action, and a physical construction was evolved which would give the necessary amount of gas and air mixture to the filament gradually and progressively to carry it on up to the ignition temperature . The instant ignition took place, all danger was automatically removed.

This lighter then is based upon the general principle of initiating a limited temperature in a platinum alloy filament by an electric current from a small dry cell, "boosting" that temperature to the kindling point of the gas by the action of the gas itself, and still keeping that temperature within the limits of safety of the filament.

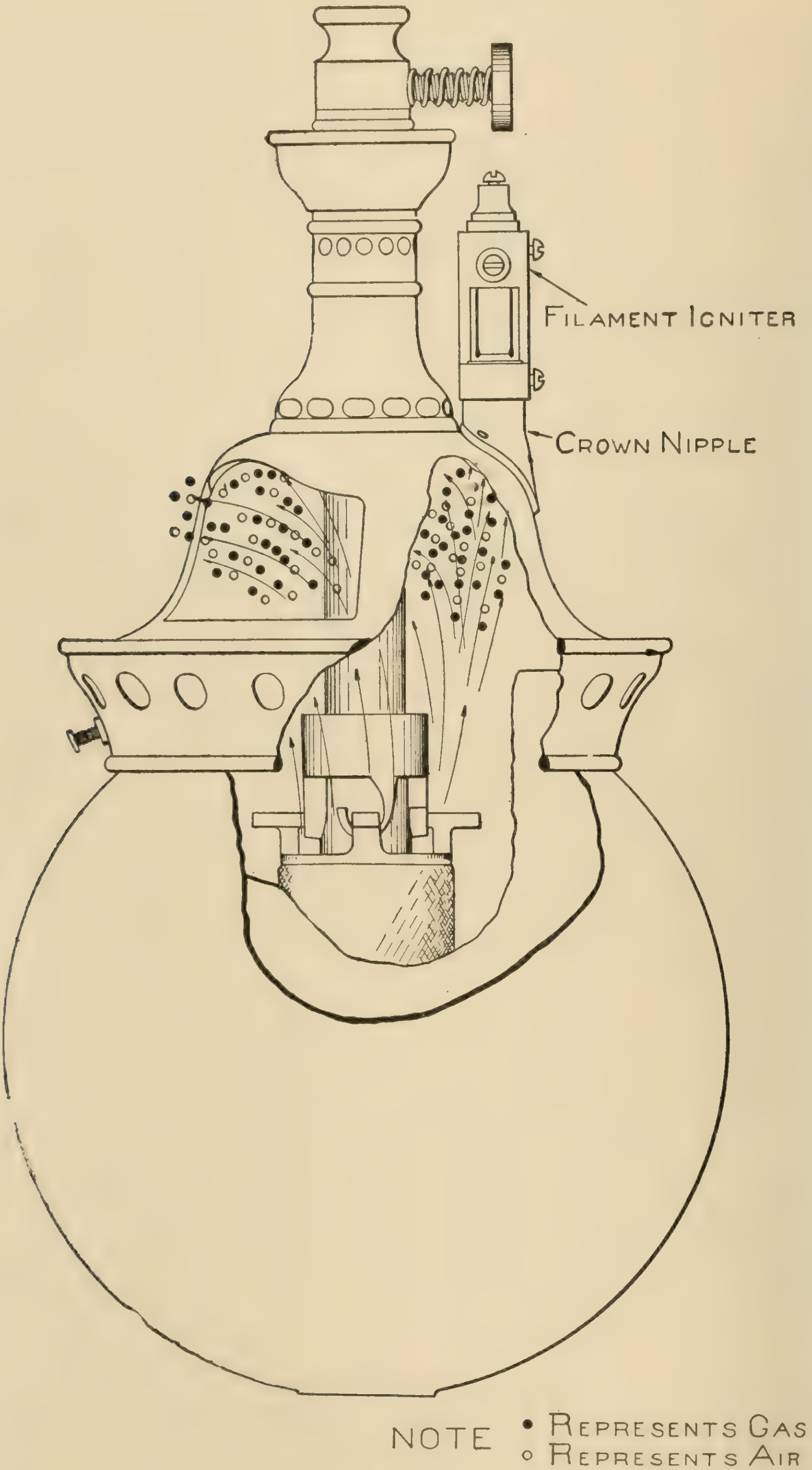

FILAMENT IGNITER
CROWN NIPPLE
NOTE
• REPRESENTS GAS
○ REPRESENTS AIR

Fig. 5.

This device is attached to some place above the orifice of the burner, so that the gas, which is lighter than air, will flow out of the orifice and up through the igniter, (Fig. 5). The wiring is arranged so that when the gas is turned on the electric circuit will be closed and the train of action started.

The simplest form of this device is shown in Fig. 6. The

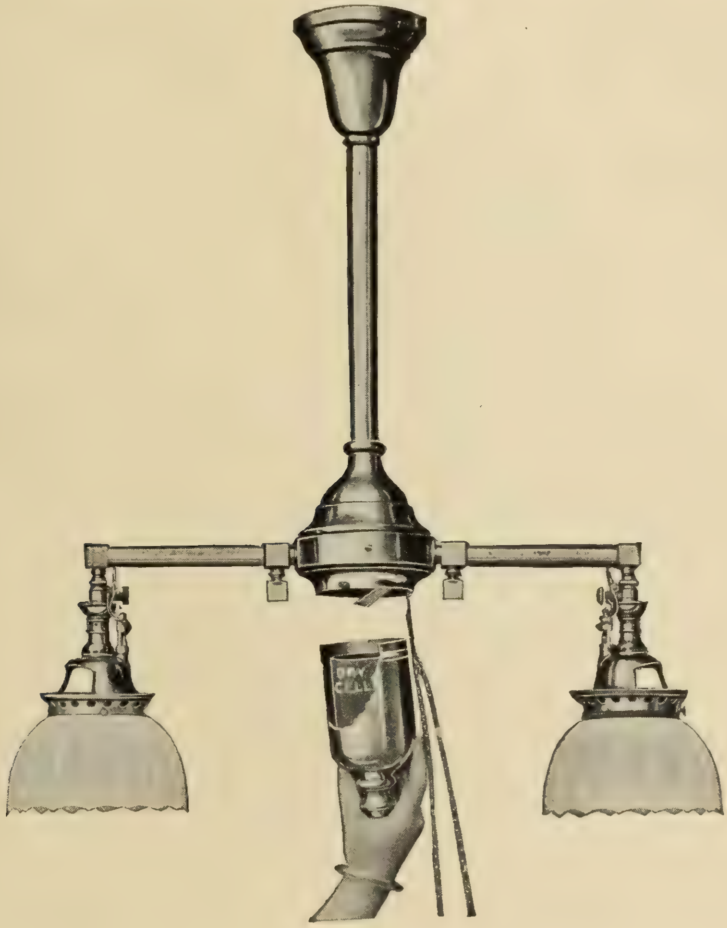


Fig. 6.

battery is stored away in the bottom shell of the fixture. A dry battery will, of course, run down in time, so it is made easily renewable. The fixture is a single-cock control, irrespective of the number of lights; the user simply pulls the chain, which turns on the gas and makes the electrical contact to all of these little igniters, one of which is on each burner. When the lighting chain is released the lever falls back and breaks the electric circuit, but leaves the gas on the burners.

Some complaint has been made about the time required to light the lamps by this system. It should be remembered that the gas has to run down through the arm, through the burner, out to the outlet and back up into the igniter, and it does not take any longer in the case of the igniter than it would with a match.

A magnetic cock has been devised by means of which gas is turned on and shut off, and attached to this cock is a little device to close the circuit to the lighter This cock is operated by a separate set of batteries, because it is essential that the battery for the lighter be constant.

Outside Lighting.—One of the next problems which has concerned the incandescent gas lighting men is the question of satisfactory outside lamps. It is not an easy matter to build a lamp which will stand the rain, sleet, wind, and the various other conditions which have to be met outside. These difficulties have been worked upon as hard as any other problems connected with illumination. To enclose an outside lamp so as perfectly to protect it from the elements comes near the point of constricted combustion. On the other hand, to open it up and give the best conditions for combustion may lead to too much exposure to the action of wind and rain. Much success has recently been attained in the construction of outside lamps, especially in inverted outside lamps.

Fig. 7, shows a five-burner outside inverted arc lamp.

Fig. 8 shows smaller unit designed for porticos and outside single units.

Individual Burners.—Single burner units are rapidly becoming standardized in two sizes: the regular type using a mantle 3.5 in. long by 1 in. in diameter, and the junior type using a mantle 2.5 in. long by 5/8 in. in diameter. The demand for burners larger than these standards with big mantles is rapidly decreasing.

The junior type burner was developed to displace the open tip. It was therefore made small and compact and adaptable to existing and standard glassware.

Fig. 9 shows the application of a "junior" in the standard open-tip gas globe.

Fig. 10, shows the application of the "junior" light in a small electric globe.

Mantles.—Recent developments in the mantle business are probably as marked as those in any other line during the last few

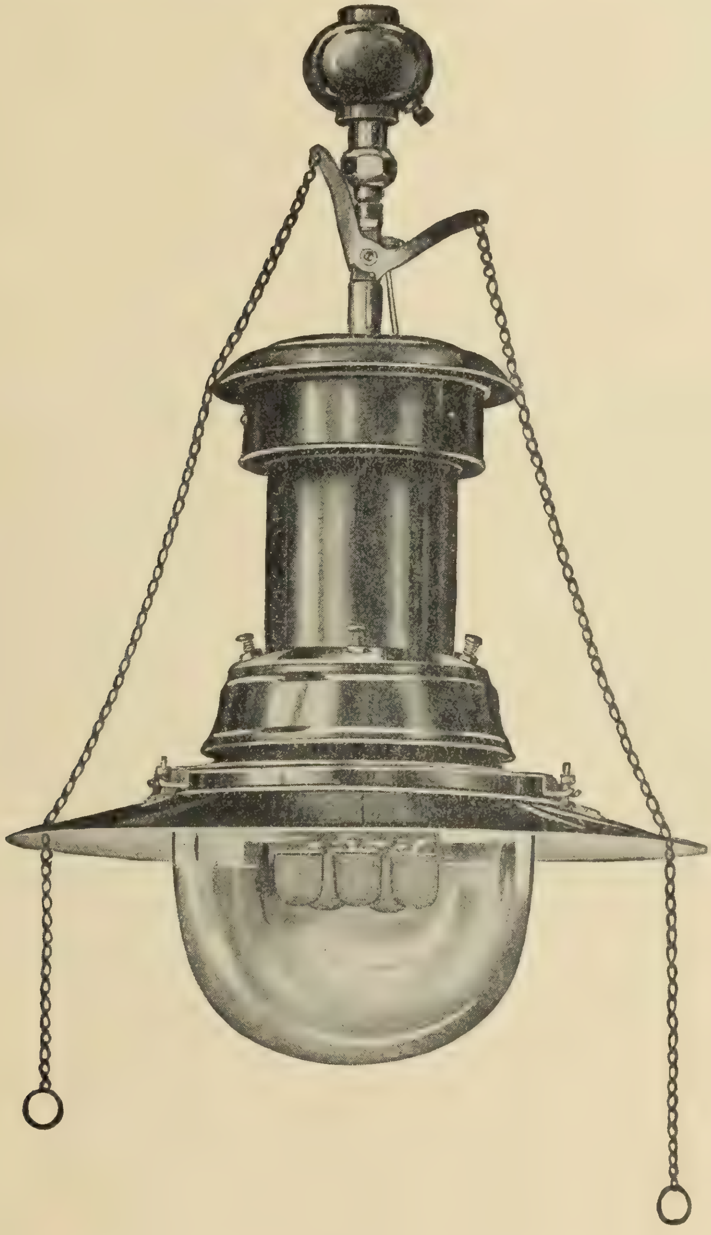


Fig. 7.

years. They begin with a study of the color valuation of the light. It is possible for the mantle manufacturer to control the color of the light from mantles within certain limits, and this can easily be demonstrated.

In store lighting, street lighting, and in public lighting there

is a demand for a white light. That demand is due probably to the fact that the recent developments in the electric lamps show a white light. The gas consumer therefore also wants a white light. Another reason is that the yellowish light has a peculiar effect on some glassware, making it look dirty, rusty, or reddish, whereas a white light makes it sparkle like diamonds or crystals.

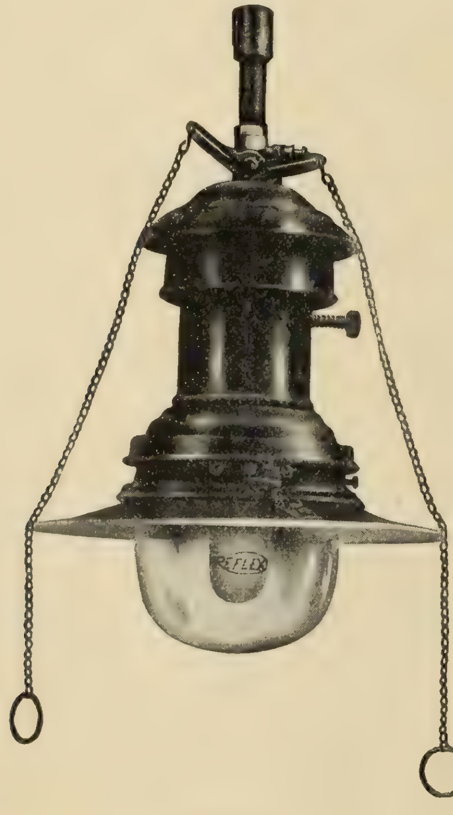


Fig. 8.

The manufacturer has been driven into the extreme of white light mantles, and the general impression exists that that is the only kind he can produce.

Mantles are made of 99 per cent. oxide of thorium and 1 per cent. of oxide of cerium. That 99 per cent. to 1 per cent. produces the most powerful light that can be got out of a mantle. The accompanying table and curve show the progressive effect of the changing chemical compositions on the candle-power, and the experiment shows the progressive color changes from purplish white to orange-yellow.

Per cent. cerium	Candle-power
0	7
¼	56
½	77
¾	85
1	88
1½	79
2	75
3	65
5	44
10	20

Fig. 11, shows the candle-power and percentages curve.

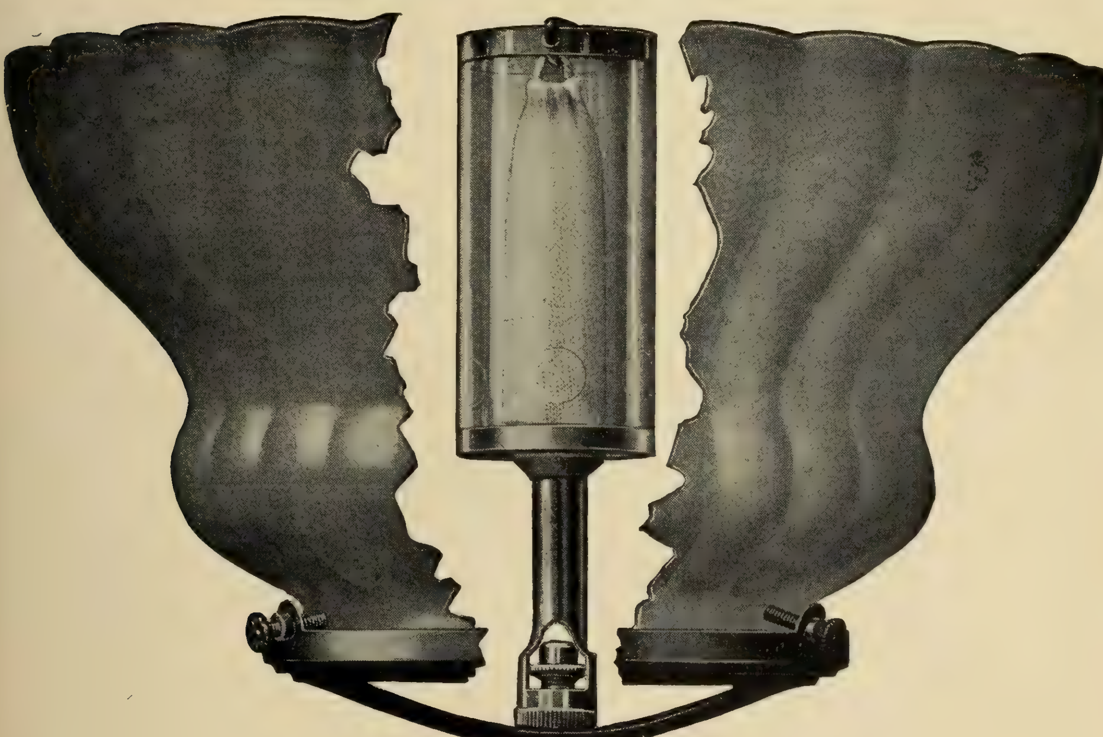


Fig. 9.

The mantles from the beginning in 1886 were made from a basic netting of cotton fabric, saturated with the lighting fluids, and the organic matter burned out. A cotton base mantle, however, shrinks and loses its shape, and its candle-power deteriorates rapidly, due not only to shrinkage, but apparently to other causes.

Ramie fibre has been substituted for cotton in many mantles and more especially in inverted mantles. Ramie is a fibre made

from China grass. The fibre has a remarkable tensile strength, and when spun into yarn makes a very strong thread, and would naturally be expected to make a strong mantle. The Ramie base mantle has improved characteristics, when compared with cotton, in that it does not shrink nor lose its candle-power to such an extent. It is more brittle, however, and this brittleness increases as the mantle is used. The candle-power of the cotton mantle

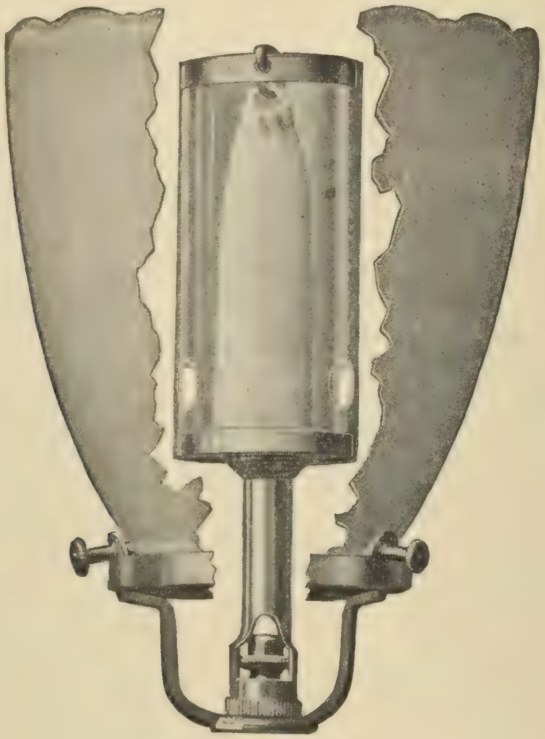


Fig. 10.

deteriorates from 35 to 40 per cent. in a 1000 hours, while the Ramie mantle only loses 15 or 20 per cent. of its candle-power.

Cotton and Ramie are both natural fibres; all other natural fibres were tried with more or less success, and we naturally turned our attention to artificial fibres as offering a means of improvement in mantles. Artificial fibres may be made from cellulose in the form of minute rods or wires, twisted together to form threads. Fig. 12 is a piece of mantle fabric made from this artificial fibre. Mantles made from this fibre radiate the original color of light indefinitely, and are better than anything yet seen in the mantle line. They do not lose their candle power,

and after 2,000 hours burning the candle-power is as high as it

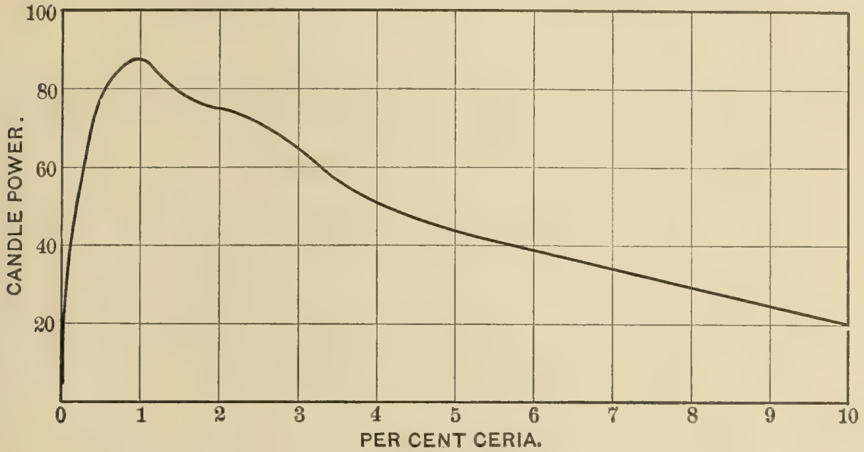


Fig. 11.—Curve showing relation of candle-power to per cent. ceria.

was in the begining. After 8,000 hours it will not have lost more than 5 or 10 per cent. of its candle-power.

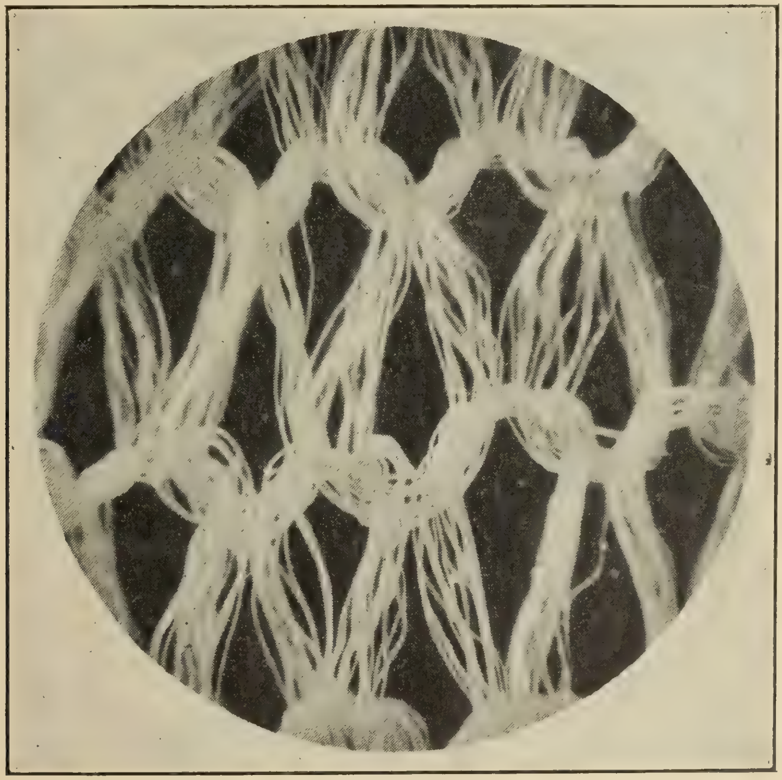


Fig. 12.

When we test a mantle, we first read its candle-power at stated

Fig. 13.

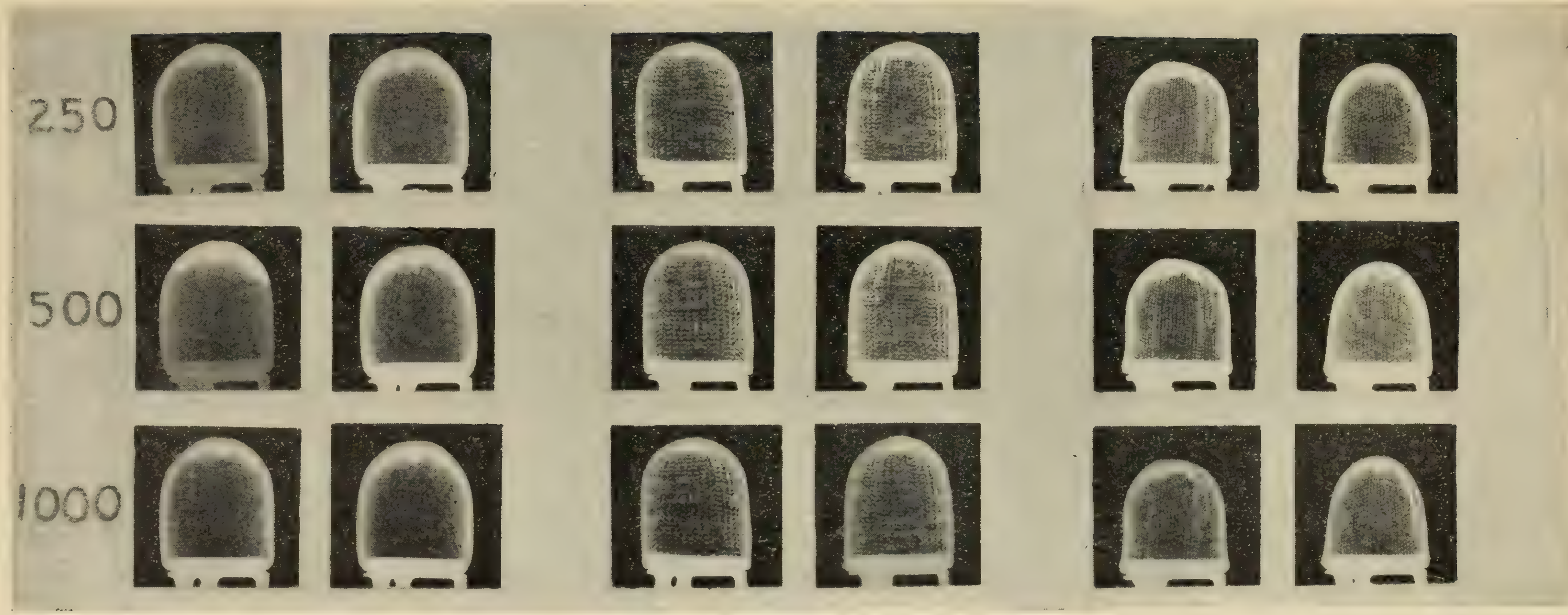


Fig. 13A.

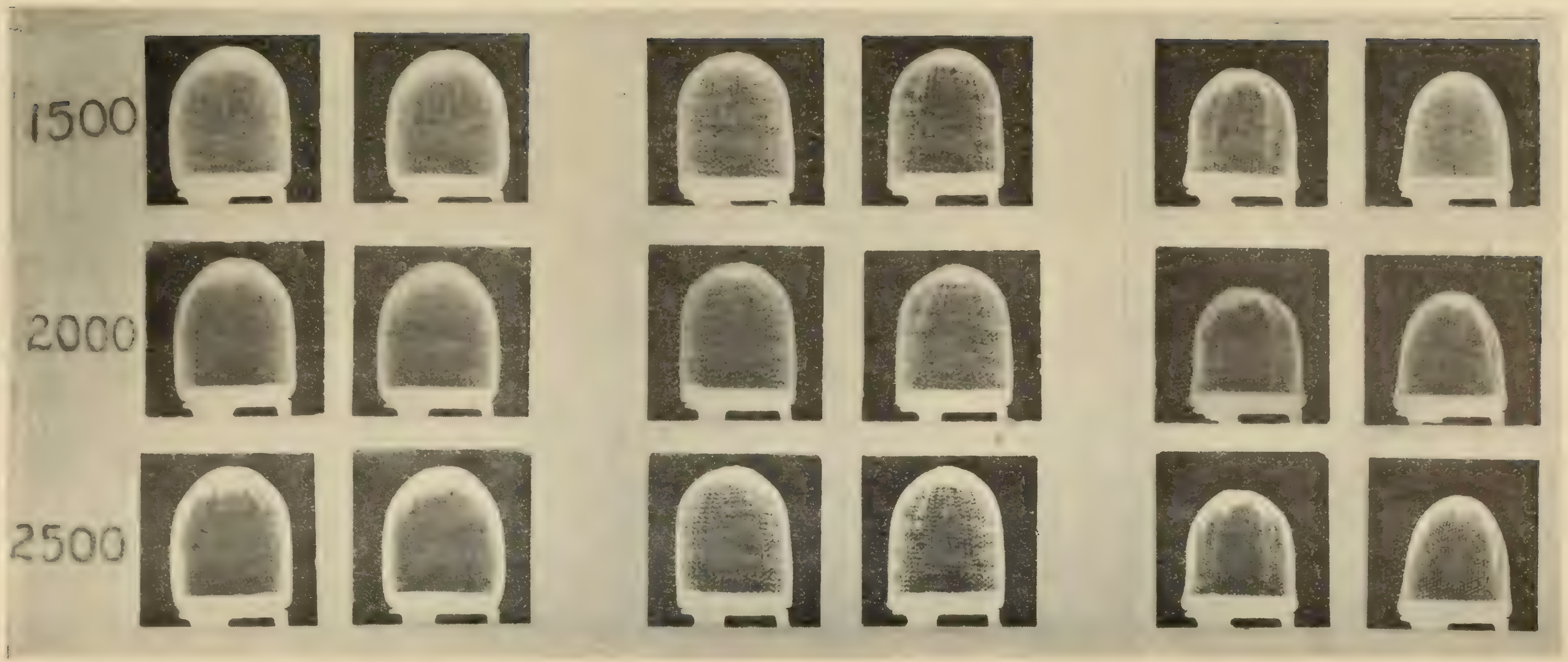


Fig. 13B.

Fig. 13C.

periods, say at the end of 100, 250, 500, 1000 hours, etc. and every time we read its candle-power we take its picture. By putting it in the same position every time we can detect any physical change that has taken place. See Figs. 13, 13A, 13B, 13C.

This cut shows the comparative condition of the three types; artificial fibre, Ramie fibre, and cotton fibre inverted mantles at

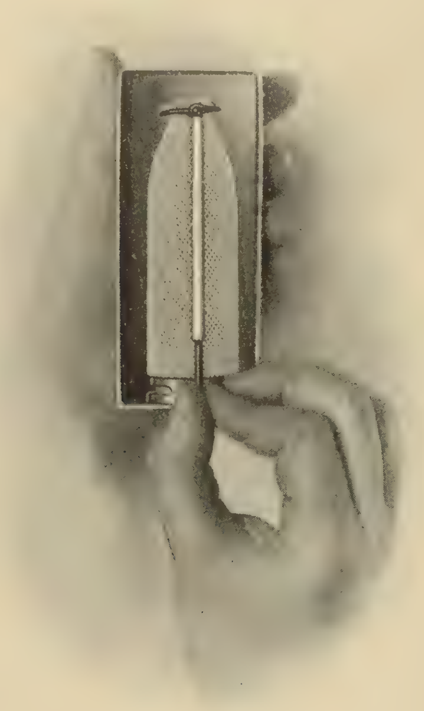


Fig. 14.

the different test stages over a period of 4,000 hours. You will note that the artificial fibre mantles have undergone practically no change in their physical shape and are still in perfect condition at the end of 4,000 hours' continous burning. These mantles are just as sound and strong at the end of the test as they were at the beginning, and the photometric observations show no loss in candle-power up to 2,000 hours and a loss of less than 10 per cent. in 4,000 hours.

The Ramie fibre mantles, while they have not undergone any material change in shape, show a decided weakness at the end of the test, as shown by the holes, which may be seen in the

picture, progressively developing. The photometric observations show a slight increase in candle-power at 100 hours with a loss of 20 per cent. at the end of 4,000 hours.

The cotton fibre mantles show a marked shrinkage and physical deformation with a consequent decrease in candle-power throughout the entire test, reaching in the aggregate over 35 per cent. at the end of 4,000 hours.

Mantle Packages.—One of the difficulties of the incandescent mantle business is the ease with which the mantles may be dam-

Fig. 15.

aged in packing and removing them from the box. The standard package for the shipment of mantles has been the round paper tube, with the paper lid top and bottom. After various unsuccessful attempts were made to eliminate the difficulty and danger attending the removal of mantles from tubes, square packages were taken up, both for the upright and the inverted

mantle. Figs. 14 and 15. These packages possess many obvious advantages over the mantle tubes.

These cursory observations represent the principle developments of the last year. The stopping point has not been reached though as we are always at the problem, and I think every manufacturer should be if he expects to stay in the business.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. V. JUNE, 1910. NO. 6

MINUTES OF COUNCIL MEETING.

JUNE 9, 1910.

The Council meeting on June 9 was called to order by President E. P. Hyde, the others present being Messrs. V. R. Lansingh, J. S. Codman, Edward B. Rosa, and A. S. McAllister.

The minutes of the previous meeting were approved. Payment of vouchers 520 to 552 inclusive, aggregating $818.84, was approved subject to the approval of the Finance Committee.

Dr. A. S. McAllister reported that he had contracted for the services of a man who would index the first four volumes of the Transactions for $100.00 and have the index ready August 1st. Thereupon the meeting resolved that the committee on indexing, Dr. A. S.McAllister, be authorized to proceed with the printing of the index for the first four years, bound separately in sufficient numbers as may be deemed advisable.

On behalf of J. Robert Crouse, Chairman of the Committee on Membership Campaign, President Hyde read a series of letters that had been prepared by Mr. Crouse for use in the campaign. The letters were approved unanimously. Moreover, the meeting resolved that a hearty vote of thanks from the Council be extended to Mr. Crouse and other members of the committee for the thorough and comprehensive plan that had been formulated. President Hyde added that Mr. Crouse said he would probably win five hundred new members from the campaign.

The Secretary's report show the following: Cash on hand, June 1st, $2562.44; accounts receivable $1743.90; accounts payable $600.02; 200 members delinquent.

The proposal that metric equivalents be placed in parentheses after all English measures given in papers presented before the

Society was discussed briefly. It was agreed that such practice would be advantageous to the Society. Moreover, it was pointed out that, inasmuch as some commercial organizations of this country had adopted this scheme, it would be well to conform to this custom. It was resolved that metric equivalents be placed in parentheses, as far as practicable, after all English measures given in the papers.

Upon motion duly seconded and carried it was ordered that the following publications be added to the Society's list of exchanges:— American—Journal of the Franklin Institute; English—The Electrician, Engineering Review, Journal of Gas Lighting, Technical Index; Canadian—Electrical News; German—Journal fur Gasbeleuchtung, Physicalische Zeitschrift; French—La Luniere Electrique; and that the Secretary make from time to time such additions to the list as he may deem advisable.

The following were elected to membership:

Foote, K. M., 115 Purchase Street, Boston, Mass.
Grant, H. E. H., British Columbia Railway Co., Ltd., Vancouver, B. C.
Morris, Roger T., 17 Milk Street, Boston, Mass.
Roberts, F. M., Fall River, Mass.

President Hyde, with the approval of the council, extended the rights of the Executive Committee to conduct the affairs of the Society during the summer. He also announced that should matters requiring especial attention arise a special meeting of the Council would be called.

Payment of an initiation fee was waived until January 1, 1911.

The following committees were appointed to care for the next convention in Baltimore:

General Committee: V. R. Lansingh, Chairman, Ira Remsen, Joseph S. Ames, Douglas Burnett, S. W. Stratton, J. S. Codman, George C. Keech, Herbert A. Wagner, Charles M. Cohn, E. B. Rosa, Charles O. Bond, P. S. Millar, and others whom the committee may deem advisable to select.

Entertainment Committee: Douglas Burnett, Joseph Ames, F. J. Whitehead, Procter L. Dougherty, H. K. Dodson, and others deemed necessary, as well as ladies, subject to the approval of the general committee.

An estimate to reprint TRANSACTIONS, of which only a few numbers are on hand, was held over until a later date.

Upon a motion seconded and carried, the President was directed to appoint a committee on Constitutional Revision. The President stated that he would announce the appointments to the committee later.

SECTION MEETINGS.

NEW YORK SECTION.

The June Meeting of the New York Section of the Illuminating Engineering Society was held on Thursday evening, June 9, in the Engineering Societies Building, 29 W. 39th Street, New York.

Chairman E. L. Elliott called the meeting to order and then asked for the report of the Nominating Committee who presented the following names for election:

Chairman, A. H. Elliott; Secretary, A. J. Marshall; Managers, S. G. Rhodes and L. R. Hopton.

On motion made and seconded the Secretary cast the ballot duly electing the gentlemen named. Dr. Clayton H. Sharp then presented the paper on "Incandescent Lamps as Standards of Luminous Intensity," prepared by him and Mr. Preston S. Millar. Dr. E. B. Rosa of the Bureau of Standards followed with his paper on "Photometric Units and Nomenclature." After an interesting discussion the meeting adjourned.

NEW ENGLAND SECTION

A meeting of the New England Section was held at Boston, Mass., on June 13, 1910. The following officers were elected to serve for the ensuing year:—Charles O. Baker, president; Wm. S. Farrow, secretary; Louis Bell and Walter G. Africa, managers. There were 15 present. A paper on "Some Matters Pertaining to Illuminating Engineering" was read by J. S. Codman, followed by a discussion.

CHICAGO SECTION

The Chicago Section of the Illuminating Engineering Society met in the restaurant of the Lincoln Park Refectory for dinner

at six o'clock, Thursday evening, June 23. The subject of the evening was a general and very informal discussion of the lighting of the Refectory.

The room is finished in a rough tan brick and ornamental Rockwood tile, the dimensions being about 84 feet by 48 feet with a trussed slanting ceiling, the highest point of which is 33 feet with a wall line approximately 21 feet high. The lighting is by two large central art glass domes, containing eight lights inside the dome and eight lights around the center of the outside of the dome. The wattage of the two domes is approximately 2,400. In addition to this there are twenty side wall clusters with opal globes, containing three 25-watt lamps each. The wattage of the side wall lights is approximately 1,200.

The balconies and verandas are lighted with small bracket lights of approximately 25 watts per lamp, enclosed in opal globes and arranged in clusters of three each. A few scattered four-light tungsten fixtures with bare lamps exposed are also used.

The musicians' balcony is lighted with several wall bracket clusters of three lights each, enclosed in globes, and one 4-light tungsten cluster with clear lamps at the head of the stairways.

Before the lighting features of the Refectory were discussed, the chairman of the nominating committee presented the following names:

For Chairman: Mr. F. J. Pearson, of Marshal Field & Co.

For Secretary: Mr. Wm. E. Kelly, of the Electrical World.

For Managers: Mr. J. G. Learned, of the North Shore Electric Company; Mr. Chas. A. Luther, of the Peoples Gas Light and Coke Company.

On motion duly made and seconded a ballot was cast and the officers nominated were duly elected for the ensuing year.

The chairman then introduced the architect of the building and a general discussion of the lighting features followed.

ACTION OF THE COUNCIL ON THE PUBLICATION OF PAPERS

At a recent meeting of the Council of the Society the following resolutions were adopted to define the Society's attitude as to the editing and publication of papers presented at the regular meetings:

Resolved, that papers read before the Society shall be released by the Committee on Editing and Publication for publication by the technical press after presentation, subject to the following conditions:—

That no paper is to be presented until it has been approved by the Papers Committee.

That no paper is to be approved for publication until printed proofs have been subjected to the usual correction by the author and by the Committee on Editing and Publication.

That no paper of the Illuminating Engineering Society is to be reprinted for commercial advertising purposes, except by written permission of the Committee on Editing and Publication.

That a periodical to be considered as belonging to the technical press must maintain a subscription list sufficient to permit it to obtain second-class postal rates.

Periodicals belonging to the technical press and answering the above description are to be given equal opportunity to reprint papers upon making written request to the Committee on Editing and Publication, and upon agreeing to state that the paper was presented before the Society.

That the committee on Editing and Publication shall be authorized to copyright any or all papers presented before the Society, and that authors of papers shall be advised that the copyrighting of papers presented rests with the Society, and that the copyright shall belong to the Society.

The following list of requirements in regard to technical papers of the Society were approved by the Council:

Papers must be submitted four weeks prior to the date of the meeting, in order to insure their presentation and to permit of the printing of advance copies.

The Papers Committee, at its discretion, is at liberty to accept

papers for Section meetings, with the understanding that the papers are not to be reproduced in the Transactions. Likewise the Committee may accept for reproduction in the Transactions, papers which are presented at technical meetings by title only.

No matter in which the advertising feature has undue prominence is admissible.

Papers descriptive of lighting installations, when such installations contain no new features, and when the papers contain no new and valuable data, are not desirable matter for the Transactions.

Previous general publication bars matter froom the Transactions, except that the Papers and Editing Committees are at liberty to depart from this rule when matter of special value is presented.

Cost discussions are acceptable only when the discussion is limited to a single type of illuminant in any one paper.

The title of a paper should be reasonably indicative of the subject of the paper.

Trade names should not be used in technical papers.

Discussions should be governed by similar rules, as far as they are applicable.

A lecture or an address may be delivered before the General Society by request of the Papers Committee, or before a Section by request of the Section Board of Managers.

Constitution, Article 7, Part 11.—The Committee on Papers shall have general supervision of all papers to be presented before the Society, and shall have the duty of preparing the programmes of general meetings of the Society and procuring papers for presentation before such meetings. No paper, discussion, communication or report shall be printed in the Transactions of the Society or elsewhere until approved by the Committee.

Part 12.—The Committee on Editing and Publication shall edit all discussions of papers presented before the Society or any section thereof, and shall decide all questions of detail regarding the publication of papers, discussions and communications. The Transactions and other publications of the Society shall be in direct charge of the Committee.

Article 9, Part 10.—Papers shall be approved by the section Board of Managers prior to presentation before a section. Manuscript of papers approved should be forwarded to the Committee on Papers sufficiently in advance of date of presentation to enable advance copies, if a paper be approved by the Committee for general presentation, to be printed and sent to all sections for distribution prior to presentation before the sections.

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A paper presented at a meeting of the New York Section of the Illuminating Engineering Society, New York, June 9, 1910.

INCANDESCENT LAMPS AS STANDARDS OF LUMINOUS INTENSITY.

BY CLAYTON H. SHARP AND PRESTON S. MILLAR.

In commercial photometry it is essential that the standard of luminous intensity be thoroughly reliable and accurate. Even where the observations on the lamps under test are of such a character that they are liable individually to considerable errors of observation, the average result on a group of a large number may be expected to be correct provided the standard of reference is correct.

The former practice in photometry of referring directly all measurements to a primary standard of light such as standard candles, the pentane standard or the Hefner standard has in recent years been superseded by the better practice of using secondary standards of reference in the form of incandescent electric lamps. Many years of experience on the part of the Electrical Testing Laboratories and of prominent makers of incandescent lamps have demonstrated that when properly seasoned and aged, when accurately standardized by comparison with authentic standards, and when correctly used, standardized incandescent lamps constitute the best reference standards for all sorts of photometrical work. They are very convenient to use, are portable, and highly accurate during a limited period of burning.

The reliability and accuracy of standards of this character have been recognized by the Bureau of Standards at Washington, in that the Bureau has adopted a set of incandescent lamps as its own reference standards. A similar recognition has been accorded by the National Laboratories of other lands.

Standardized incandescent lamps having thus become the most important photometric standards, the proper methods of preparation and of use of such lamps is a matter of fundamental interest in the science. In view of the long experience, extending over thirteen years or more, in the preparation and use of standardized incandescent lamps which the Electrical Test-

ing Laboratories has enjoyed, and considering further the widespread employment of lamps standardized by the Laboratories, and of the very great importance in the industry of the lamp tests which the Laboratories make, it has seemed desirable to place in the records of the Illuminating Engineering Society an account of the methods which the Laboratories employ in the selection, preparation and use of standard lamps. This is particularly true since any connected account covering the proper methods to be used in work of this character is lacking.

SELECTION OF LAMPS

No lamp is accepted for standardization without having passed a rigid inspection whereby all lamps which are in any way imperfect are eliminated. It is particularly important that in each lamp the vacuum shall be high and the filament free from visible imperfections. Moreover, its mechanical construction must be good, that is, the base must be properly fitted, the filament must be mounted in the vertical axis of the lamp and must be symmetrical. The base must conform strictly to standard dimensions in order that good contact in sockets and receptacles will be secured.

SEASONING.

The life history of carbon lamps burned at constant voltage shows that for a short period of time at the outset their candle-power increases. Following this increase is a certain limited period during which the candle-power is practically constant, after which it begins to decrease. This relatively short period of constant candle-power represents the useful life of a standard incandescent lamp at given voltage.

The seasoning of a lamp consists in burning it during its period of initial rise in candle-power; that is, until the candle-power of the lamp has reached its short constant period. The method which has been followed in the past in seasoning lamps has been to measure the candle-power of the lamp at short intervals during its initial period. When the candle-power has shown a constant value it has been considered that the lamp was seasoned. This method, when carefully followed, yielded good results. It is open to the objection that the preliminary pho-

tometric measurements during the seasoning process must be made with considerable care, and consequently add to the cost of standardizing the lamp. Another method is now being adopted which promises better results and which is founded on the following considerations:—

In any given lamp, when the vacuum, the character of the surface of the filament and the transparency of the bulb are unaltered, the candle-power depends directly upon the watts expended in it. During the early life of the lamp, the watts expended in the lamp at constant volts changes on account of a decrease in the resistance of the filament. When the filament has become stable, that is, when its resistance no longer decreases, the candle-power at constant volts no longer decreases. Now, the measurement of electrical resistance is the most precise, as well as the most convenient measurement which can be made. The method therefore has been adopted to measure the change in resistance of the filament at full voltage rather than the change in candle-power. The total change in resistance of a lamp in the period between its initial and peak candle-power is, roughly speaking, 0.5 per cent. To obtain a satisfactory determination of the exact point at which the seasoning process should be interrupted, the change in electrical resistance should be measured to something like one or two per cent. It is necessary, therefore, that the electrical resistance should be measured accurately to one part in 10,000 to 20,000. There are two available methods for measuring this resistance change. One is to measure the voltage and current. When the current ceases to change at constant voltage, the seasoning is ended. It is, however, a matter of some difficulty to measure the current through a lamp to one part in 10,000. To do it requires that a very steady source of electromotive force should be available and that two precision potentiometer should be used in the work. The other method, which is the one that has recently been developed at the Laboratories, is to use the Wheatstone bridge method, a method which is easily capable of yielding results to the required precision, and which does not require an absolutely steady applied voltage. In using this method the lamp is connected in series with a manganin resistance having about the same value as the

hot resistance of the lamp. Around the two is looped a variable resistance with a total of approximately 10,000 ohms. A suitable pivoted galvanometer gives ample sensibility. The current through this bridge is adjusted to the value which will bring the lamp to its full incandescence. This adjustment is easily made with the requisite precision. Since a treated carbon filament at its temperature of full incandescence has quite a small temperature coefficient, a deviation from the correct value of current affects the result only to a minor degree. Using this apparatus, the change in the resistance of the lamp during the seasoning process is determined and is shown on cross section paper When the curve of resistance has become parallel to the axis of time, the seasoning is completed. This point is determined with great nicety, hence a shortening of the useful life of the lamp due to over-seasoning is not to be feared.

It may be noted in this connection that if lamps are standardized at given watts instead of given volts, their useful life is greatly extended. However, the greater inconvenience of bringing a lamp to given watts rather than given volts is such that it is usually preferred to use the standardization by volts. When in a standard lamp, the ratio of the voltage to the current has changed, it may be confidently asserted that the candle-power of the lamp at constant volts also has changed, and that either the lamp must be restandardized or the standard voltage altered until the lamp once more burns at the original watts.

THE PHOTOMETRIC UNIT.

The photometric standards of the Electrical Testing Laboratories have an interesting history. On the organization of this Company, its photometric standards were obtained by copying a set of master standards in the possession of one of the large companies manufacturing incandescent lamps. The lamps so copied had been standardized about 1890 at the Physikalisch-Technische Reichsanstalt in Berlin. By frequent careful recopying and intercomparing, the value of the line of standards so established has been kept constant until the present time. This constancy was first verified in 1902 by means of lamps standardized in the Laboratories and sent to the Reichsanstalt for verification. Similar verifications have been made subsequently to

that time. Indirect comparisons of this kind have been made through the Bureau of Standards and no decided variations from constancy have been shown. In 1903, six of our standard lamps were taken to the National Physical Laboratory in England, to the Laboratoire Central d'Électricité in France, and to the Reichsanstalt in Germany and compared with the standards in use there.[1]

The results of this comparison are summarized in the accompanying table.

It will be seen that the lamps were in good agreement with the Reichsanstalt standards assuming the ratio of the value of the Hefner unit to the candle which had been taken at the time that the progenitors of the line were originally standardized in 1890 (namely, 1 hefner = 0.88 c-p.). Moreover the value of the Bougie decimale as used in France was substantially equivalent to the candle as used in America. In regard to the English standards it should be noted that at the time the above comparison was made the photometric department of the National Physical Laboratory was in process of organization and had not as yet settled upon the standards which it was to use. In lieu of better standards, Fleming large bulb standard lamps which had been standardized under Dr. Fleming's directions were employed, so that the comparison given is really a comparison of the standards of the Electrical Testing Laboratories with the Fleming standard, and not with the official standards of the National Physical Laboratory. As admitted later by Dr. Fleming these standards were considerably in error because in standardizing them he had neglected to take account of the marked changes in the luminous intensity of the pentane lamp with change in humidity content of the atmosphere.

Not long after this the National Physical Laboratory derived its own set of authentic standards by comparison with the pentane lamp, taking account of the variable elements. The value of the unit so derived was determined by measurements made by them on standard lamps of the Electrical Testing Laboratories, sent to them for that purpose. These measurements showed that a lamp measuring 16-c-p. at the Electrical Testing Lab-

[1] The Equipment of a Commercial Testing Laboratory, by Clayton H. Sharp, Transactions International Electrical Congress, St. Louis, 1904, Vol. I, page 500.

Lamp No.	Nat. Phys. Lab. C-p. C. C. P.	Nat. Phys. Lab. Fleming standards Nos. 9 and 16 as reference standards C-p. C. H. S.	Pender Fleming standards C-p.	Ediswan Fleming standards C-p.	Ediswan 10-c-p. pentane lamp standard C-p.	L. C. E. Bougies decimales	P. T. R. Hefner candles reported	P. T. R. Values actually observed	P. T. R. Assuming that I. H. K. = 0.88 c-p. C-p.	E. T. L. Jan. 8, 1904 C-p.	National bureau of standards C-p.
1....	16.87	...	17.17	17.6	17.9	...	18.0	18.03	15.87	15.85	15.85
2....	16.87	...	16.91	17.9	18.05	16.1	18.1	18.12	15.95	16.04	15.9
7....	16.74	16.88	17.03	17.4	17.55	...	18.1	18.05	15.88	15.99	15.8
11....	17.06	17.04	17.15	...	...	16.3	18.2	18.19	16.00	15.99	15.95
15....	16.87	16.98	17.27	...	...	...	18.1	18.14	15.96	15.89	16.0
17....	16.94	...	17.13	...	...	...	18.2	18.24	16.05	16.01	16.0
Mean.	16.89	16.97	17.11	17.6	17.8	16.2	18.12	18.13	15.96	15.96	15.92

oratories, measured 16.11-c-p. at the National Physical Laboratory.

The Bureau of Standards at Washington, on its inception, adopted the practice of maintaining its photometric unit by means of incandescent lamps, just as the Electrical Testing Laboratories had been doing, and it also adopted the same value of the unit of light. Subsequently it was found that the unit which the Bureau of Standards had adopted and which was the unit in general use in the electrical industry in this country was not in agreement with the most authentic standards employed in the gas industry. The most reliable value of the candle-power in use in the gas industry was that given by the Harcourt 10-c-p. pentane lamp. It was found that the candle-power as derived from the pentane lamp was about two per cent. smaller than that adopted by the Bureau of Standards. This matter was taken under consideration by a joint committee representing the Illuminating Engineering Society, the American Institute of Electrical Engineers and the American Gas Institute. As a result of the recommendations of this committee, action was taken by the responsible boards of these three engineering societies in passing a resolution in which the Bureau of Standards was urged to change its unit by an amount not to exceed two per cent. so as to bring the value of the candle as used by the gas and electric industries in this country, to a common basis.

In the meantime, the Bureau of Standards had been making intercomparisons with the other National Laboratories, using incandescent lamps in the way which the Electrical Testing Laboratories had already done and had discovered that a change in the value of the candle unit such as was required to bring the gas and electric industries in this country into uniformity, would serve also to place the National Laboratories of England, France and America on the same basis. An agreement with the authorities in the other National Laboratories was made by the Bureau of Standards, whereby the Bureau agreed to lower its standard by 1.6 per cent, in order to secure the desired uniformity and at the same time the foreign laboratories agreed to abide strictly by the value thus determined. Thus was not only national but also international uniformity secured.

Following as soon as practicable this national authority, the Electrical Testing Laboratories on the 1st of May, 1910, changed its unit by a corresponding amount, and has issued from that date all standard lamps in terms of the new unit. This is 1.6 per cent. smaller than the unit which the Company has been using during the previous years of its existence.

STANDARDIZATION.

In standardizing seasoned lamps, the standard value is assigned as determined from a series of separate and distinct comparisons with the laboratory standards. These comparisons are made at different times, by different photometrists and usually upon different photometers. The number of determinations made is proportional to the degree of accuracy with which it is desired to standardize the lamps.

For this work standard photometers in a special room are used. These photometers are equipped in accordance with the most exacting requirements of modern practice. The photometer heads are of the most sensitive type, the graduations of the bars are very carefully checked, the utmost care is used in screening stray light from the photometer discs, and finally the electrical measurements are made directly against a standard cell and standard resistances by the use of potentiometers. The lamp sockets in which the lamps to be standardized are placed, are so constructed that the voltage measured is the voltage on the shell of the lamp itself, so that no voltage drop in connecting wires, contacts, etc., is measured in with the voltage of the lamp. The mean horizontal candle-power of lamps is determined usually by measuring them when rotating at approximately 180 revolutions per minute. Stationary standards (See Fig. 1) have vertical lines etched on opposite sides of their bulbs, and such lamps are properly oriented by sighting across these two lines at the photometer disc, or at the comparison lamp at the far end of the photometer bar.

Standards of mean spherical candle-power are standardized by taking a series of measurements of the rotating lamp at various angles above and below the horizontal plane of the lamp. From these measurements, mean spherical candle-power is computed. These lamps are also subjected to a series of measurements in

an integrating sphere in which they are compared indirectly with the mean spherical standards of the Laboratories.

In the certificates which are issued with standard lamps, the voltage, current at that voltage and candle-power are given. In practice, it is necessary to make sure that the lamp when at its proper voltage, is consuming exactly the given amount of current or that it is consuming the proper watts; otherwise its condition is not standard.

TYPES OF LAMPS.

In most commercial photometric work carbon filament lamps of the ordinary oval anchored type, standardized rotating, form acceptable standards. For work of higher precision and for sta-

Fig. 1.

tionary standards in general, the Electrical Testing Laboratories have developed a special type of lamp which has proven satisfactory. (See Fig. 1). This consists of two hairpin loops, one within the other, and lying in the same plane. The idea of this form of construction is to render it possible to determine the dis-

tance between the photometric center of the lamp and the photometer screen with the highest degree of precision. In the oval anchored type the different parts of the filament lie at different distances from the photometer screen; hence this distance cannot be determined with high accuracy. The filaments of the parallel filament type of lamp, which is illustrated in Fig. 1, lying as they do in the same plane at right angles to the axis of the photometer bar, enable the operator to get this distance very exactly. Moreover in this style of lamp the variation of the candle-power involved in a false adjustment of the lamp whereby it is not placed with its filaments exactly at right angles to the bar is very small, and the consequences of a mistake of this kind are minimized.

Ordinarily in the interests of long life, carbon filament lamps are standardized operating at about 4 watts per candle. This involves the disadvantage that the light of the lamp is somewhat redder in hue than that of most of the lamps which are to be compared with it, though this disadvantage is not a very serious one until metal filament lamps are reached. The comparison of a tungsten lamp at 1.25 watts per candle with a carbon lamp at 4 watts per candle involves very great uncertainties on account of color difference. On this account the Laboratories have as a result of many measurements by many observers and by intercomparison with other laboratories,[1] established a set of tungsten standards, the candle-power of which is known in terms of the carbon standards. The color difference difficulty having been met once for all, is eliminated in future work with tungsten lamps by the use of tungsten standards.

A great deal of attention has been given recently to the question of standardizing tungsten lamps, since this type of lamp being very little subject to change in candle-power, would seem to make an ideal standard, not only for the measurement of tungsten lamps, but also for carbon lamps as well. In the latter case the tungsten standards would be standardized at a sufficiently reduced voltage to bring their color to the right quality. It has been found that the ordinary commercial type of tungsten lamp does not admit of very accurate standardization. The difficulty seems to be that

[1] The Problem of Heterochromatic Photometry, by Preston S. Millar, *Transactions*, Vol. IV, page 769.

a variable cooling is introduced by the contacts between the filament and the anchoring wires. To meet this difficulty the Laboratories have developed a type of parallel filament tungsten lamp in which the anchor wires are dispensed with and all variable contacts are removed. This type of lamp, which is illustrated in Fig. 2, is available only in low voltages, but from all

Fig. 2.

indications furnishes a reliable standard. Another type of tungsten lamp standard has been developed, in which the filaments are in the form of straight pieces welded to wires both at top and bottom. This plan also obviates the variable contacts and enables the construction of lamps of the 100 to 130 volt range.

The Electrical Testing Laboratories has had made to its specifications miniature tungsten lamps in large bulbs for operating on battery current. These lamps when seasoned and standardized find some important applications in photometry, particularly in connection with portable photometers.

STANDARD AMPERE LAMPS.

Incandescent lamps, when properly seasoned and standardized

make very acceptable standard resistances for current measurements by the fall of potential method. For a limited period their resistances remain constant and they form very accurate standards of amperes.

In the use of lamps in this matter it is essential that the voltage shall be accurately determined. This is a simple matter in a well equipped laboratory having laboratory standard instruments. The indications of every voltmeter which is designed in any sense for use as a standard or from which it is desired to obtain accurate results, should be verified periodically and a correction curve showing the error of the instrument at various points throughout its scale should be provided. By the use of such a correction curve most errors usually encountered in the use of voltmeters can be avoided.

In determining the current consumption of incandescent lamps the use of standard ampere lamps is recommended, as this practice possesses the advantages of the substitution method in photometry and affords a correction for errors in the electrical instruments used.

ACCURACY OF STANDARDIZATION.

In view of the fact that much photometric work is done in which is not essential that the standards employed should be of the highest precision, the Electrical Testing Laboratories issues standards of two grades. In the precision standards the accuracy of the electrical measurements is certified to one-tenth of one per cent., corresponding to a photometric accuracy in the case of carbon filament lamps of about six-tenths of one per cent. Standardization to this degree of refinement requires a long series of careful measurements extending over considerable time. In the commercial standards the certification is to one-fourth of one per cent., corresponding to a photometric accuracy of about 1.5 per cent. This degree of accuracy being greater than is obtained in much commercial photometric work, is sufficient in many cases.

METHODS OF USE.

In all, or nearly all, photometric measurements, the "Substitution method" should be employed. This method is in every way superior to direct comparison which is the traditional method in photometry.

In operating by the substitution method the lamp at one end of the bar is simply a constant source of light; for example, an incandescent lamp of convenient intensity held at constant voltage. At the other end of the bar is placed first the standard lamp which, when brought to its standard voltage and current, is compared with the constant comparison lamp at the other end of the bar. If the bar has a direct reading scale, the comparison lamp may be adjusted until the reading on the bar equals the candle-power of the standard lamp; then the bar indicates the candle-power of all lamps subsequently tested on it. Having thus standardized the apparatus by the use of one, or preferably several standard lamps, the lamps which are to be measured are substituted for the standard lamp; that is they are placed in the same socket and their voltage is measured by the same instrument. Operating in this way, the standard lamps themselves are used only for a very brief period of time, and many sources of error, both photometrical and electrical, are partially or wholly eliminated. The personal equation, reflections of light from the photometer table, walls and ceiling, lack of symmetry in the photometer, slight inaccuracies in the electrical instruments, as well as most other sources of error, apply to the standard lamp measurements in a similar manner and to a similar degree as to the measurements of the lamps which are under test, and are therefore to a large degree automatically compensated. If at any point the photometric apparatus involves the use of mirrors, the substitution method also takes account of their absorption.

To obtain the best results in the photometry of incandescent lamps, the usual precautions in photometric work must be taken, and in addition the following instructions should be carefully observed.

The standard lamps employed should be of the same general type and approximately the same voltage and current as those which are to be photometered. The most important point to be observed is that their filaments are of the same character and material as the filaments of the lamps which are to be measured. Where standard lamps are to be used for purposes of investigation or for comparison with sources of light other than incandescent electric lamps, other considerations may influence the selec-

tion of the standards. In any case at least three, and preferably more, standard lamps should be included in the series. This enables inter-comparisons to be made, guards against error and against interruption of work due to the failure of a standard lamp.

Care should be taken that good contact is secured between the lamp base and its receptacle, and that the parts which are relied upon to make electrical contact should be electrically clean.

It is also important that the voltmeter leads should be connected as near as possible to the lamp terminals, since any fall in potential between the point of connection and the lamp shell is measured in with the voltage of the lamp.

If the standard lamp is to be used in a fixed position it should be so placed that the axis of the lamp filament is vertical and the fiducial lines etched on opposite sides of the bulb are accurately in line with the center of the photometer disc. If the lamp is to be rotated it should likewise be mounted so that the axis of the filament is perpendicular to the bar and remains so while rotated.

It is very desirable that the source of current for the photometry of incandescent lamps should be a storage battery, though by proper arrangement of circuits it is possible in work of ordinary commercial character, to use a supply from a dynamo.

The standard lamps used should be rated for a somewhat lower voltage than the voltage of the supply, so that a finely divided rheostat can be included in the circuit for the purpose of adjusting accurately the voltage on the lamps. Before closing the standard lamp circuit, care should be taken to introduce enough resistance to avoid possibility of burning the lamp at a higher voltage than that at which it is rated. Failure to observe this precaution may result in shortening the useful life of the lamp as a standard of light. If subjected, even for an instant, to an abnormally high pressure, its usefulness will, in general be destroyed.

The circuit once closed, the voltage upon the lamp should be increased until its standardization voltage is reached, when the current flowing through the lamp is measured. Knowing the resistance of the voltmeter and the voltage across it, the value

of the current taken by the voltmeter may be computed, and this voltmeter current when it is included in the current measured by the ammeter, must be subtracted from the indication of the ammeter. If the lamp current is then found to be greater or smaller than that specified in the certificate, the indication is either that an error exists in the voltmeter or ammeter used, or that the standard lamp has changed. Reference to the other standard lamps in the series will then indicate whether the error lies in the first standard lamp or in the electrical instruments. If the standard lamps are found to be in good agreement among themselves and the discrepancy still exists, it is fair to assume that one or both of the electrical instruments are incorrect. If the work is being carried on by the substitution method, the lamps to be measured being of the same type as the standard lamps, it is permissible, in lack of better information, to assume that the voltmeter is correct and that the error lies in the indications of the ammeter, and to apply to the ammeter a sufficient correction to make its indications conform to the data in the standard lamp certificate. This assumption will lead to fairly good results even though the voltmeter is actually somewhat in error, provided, as is usually the case, the percentage error of the voltmeter is constant throughout the range covered by the lamps which are being measured, since a given percentage error in voltage will affect the standard lamps and the test lamps alike.

For precision work in photometry it is necessary that the electrical measurements shall be made with a high degree of accuracy. Where electrical instruments of precision, such as the potentiometer with its adjuncts, are not available, correction curves showing the errors of the ammeter and voltmeter used, as determined by comparison with primary standard instruments, form fairly acceptable substitutes. When the corrections to the electrical instruments have been applied, the indications of these instruments should be found to agree with the certified standard lamp values.

If upon intercomparison, one or more standard lamps are found to differ from the other lamps in the group, they should be replaced at once by newly standardized lamps. If it is found that the current flowing through the lamp when it is brought to its

standard voltage, differs from that given in the certificate, it follows in general that its candle-power has changed; conversely, if a lamp consumes the stated current when operated at the stated voltage, it is fairly safe to assume that its candle-power has remained unaltered.

It is hoped that the facts given above will lead to a more general understanding of the possibilities of incandescent lamps as standards of candle-power and of a greater appreciation of the precautions which are to be taken in their use, both in commercial photometry and in photometry of precision.

A paper presented at a meeting of the New York Section of the Illuminating Engineering Society, New York, June 9, 1910.

PHOTOMETRIC UNITS AND NOMENCLATURE.

BY EDWARD B. ROSA.

The subject of photometric units and nomenclature has attracted some attention recently in the technical press, and a wish has been expressed by more than one writer that there might come into use a more systematic and uniformly accepted nomenclature. Hering, who has given the subject a good deal of attention and has published some valuable articles on it, remarks that many writers are vague in their expressions, using such terms as intensity, quantity, brightness, illumination, flux, etc., in quite different senses. He says:

> Moreover, the application of these useful laws (of light distribution) would be much better understood if we had a clearer physical conception of what these various quantities really mean, instead of merely calling them by indefinite names.

The following discussion is an attempt to bring out the physical meaning of the various quantities referred to, and to show that some of the names of units that have been objected to are really useful and contribute to clear thinking. Many of the theorems derived are not new, but they are nevertheless useful in developing the desired relations between the various photometric quantities. Acknowledgment is made to Blondel, Palaz, Liebenthal, Hering, Kennelly, Sharp, Hyde, Jones and others, whose writings and discussions have done much to develop the subject.

In what follows some of the names are used in a different sense from that ordinarily obtaining, and slight changes have been made in some of the symbols. These changes are in the interest of a more systematic arrangement, and it is hoped they may not be found confusing.

GENERAL DISCUSSION AND DERIVATION OF FORMULAS.

1. *Point source.*—We start with the idea of a luminous flux radiating from a point source. Experiment shows that the illumination produced by such a source varies inversely as the square of the distance from the source. We define the illumina-

tion as the quantity of the luminous flux falling upon a unit of area.

A point source of light of intensity I produces a luminous flux in every direction, the numerical value of which at any given distance is proportional to the intensity I and inversely proportional to the square of the distance. Thus putting E for the *illumination* at a distance r

$$E = \frac{I}{r^2}. \qquad (1)$$

If the light source is at the center of a sphere, the entire inner surface is uniformly illuminated; the light may be said to flow out uniformly in all directions, and the space to be filled with a luminous flux. The total flux falling on the inner surface of the sphere is the product of the illumination, or flux per unit of area, E, times the total area. Putting F for the total *luminous flux* it follows that

$$F = 4\pi r^2 E$$

or, by equation (1)

$$F = 4\pi I. \qquad (2)$$

The intensity I is measured in *candles,*[1] the flux F in *lumens,* and the distance r in centimeters. In practice r is often measured in meters or in feet. Thus from a point source of intensity I *candles,* there is a luminous flux $4\pi I$ *lumens.* This is analogous to the flux of 4π lines of magnetic force from each unit of magnetism, and of 4π lines of electric force from each unit of electricity, in electrostatics.

The *flux density* is the luminous flux per unit of area normal to the flux, or the total flux F over an area divided by the area S; thus the flux density is $\frac{F}{S}$, or $\frac{dF}{dS}$ when it is variable.

If the source is not a point but a small sphere of radius a, the flux $4\pi I$ passes out from a radiant surface $4\pi a^2$. Thus the flux density of radiation or the *specific radiation,* is

$$\frac{F}{S} = \frac{4\pi I}{4\pi a^2} = \frac{I}{a^2} = E'.$$

[1] It is proposed to call the new value of the American candle, which is the same as the English candle and the French bougie decimale, and which is also used by several other countries, the International candle.

Thus, we may speak generally of the luminous radiation at any point in space, and of the flux density of such radiation. If it falls on a material surface the incident flux density is the *illumination* E; as it comes from a luminous or other radiating or diffusing surface, the flux density is the *radiation*, E′. Although E and E′ are quantities of the same nature, it is convenient thus to distinguish them, as we shall see farther on.

The luminous flux density in space is analogous to electric displacement in electrostatics, the illumination on a material surface is analogous to surface density of electric charge. We think of an electric displacement as occurring everywhere in space about an electric charge, but a surface density σ occurs only where there is a material conducting body on which the lines of electric force terminate. In the same way the terms luminous flux and flux density apply generally. The *radiation* is the flux density at the source of the flux, and the *illumination* is the flux density or flux per unit of area on the surface where the luminous flux is received.

2. DISTINCTION BETWEEN LUMINOUS FLUX AND ENERGY.

The total luminous flux F is not to be confused with the total energy flowing from a luminous body. Luminous flux, or *light* as we ordinarily say, is the physical stimulus which applied to the retina produces the sensation of light. It is equal to the radiant power multiplied by the stimulus coefficient. This stimulus coefficient is different for every different wave frequency or wave length, and is of course zero for all frequencies outside the visible spectrum. Hence, if W_λ is the power (expressed in watts) for unit of wave length of the spectrum, and K_λ is the stimulus coefficient or *luminous efficiency* whose value varies with the wave length λ, we have for the total power radiated from a body

$$W = \int_0^\infty W_\lambda \, d\lambda$$

and for the luminous flux

$$F = \int_{\lambda_1}^{\lambda_2} K_\lambda \, W_\lambda \, d\lambda$$

where λ_1, and λ_2 are the wave lengths at the limits of the visible spectrum.

As the values of K_λ throughout the spectrum are not accurately known, it is not possible to calculate F in general. But by measuring W in watts and F in lumens, we can determine the ratio of the luminous flux to the radiant power in any particular case. One may properly say that luminous flux is due to and is always associated with radiant power measured in watts: but the statement sometimes made that luminous flux and radiant power can be converted into one another like feet and inches is misleading; for, as stated above, the conversion factor, the stimulus coefficient or luminous efficiency, is not a constant like the ratio of feet to inches, but is variable, having a different value for every different wave length in the visible spectrum and falling to zero outside the visible spectrum.

3. DEFINITION OF INTENSITY.

If the source is not symmetrical, but sends out a total luminous flux F unequally in different directions, then the mean value of the *intensity* is called the *mean spherical intensity*, and its value is

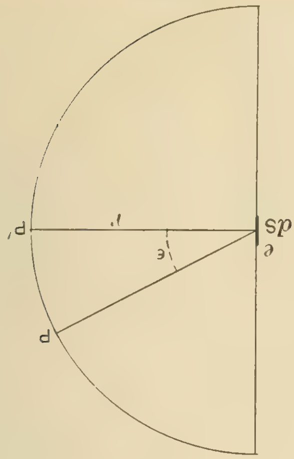
$$I_s = \frac{F}{4\pi}. \qquad (3)$$

We thus define the mean spherical intensity with respect to the total flux: and similarly, the intensity I in any particular direction is the ratio of the flux through a small solid angle in that direction to the angle. Thus

$$\left.\begin{array}{l} I = \dfrac{F}{\omega}, \ \omega \text{ being a solid angle,} \\ \text{or } I = \dfrac{dF}{d\omega}, \ d\omega \text{ being an infinitesimal solid angle.} \end{array}\right\} (4)$$

In the case of a point source or unit sphere radiating equally in all directions, the intensity I is defined as the flux through a unit of solid angle, or steradian, that is, $I = F$ when $\omega = 1$. This is an angle subtended by $\frac{1}{4\pi}$ of a spherical surface, and in the case of a conical angle its section through the apex is a plane angle of 65° 32′ 28″.

Fig. 1



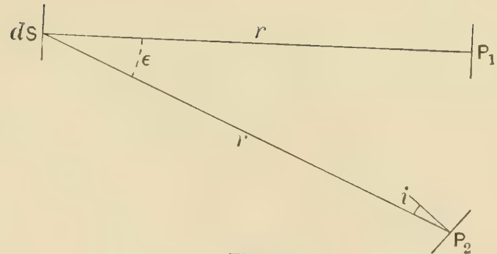


Fig. 2

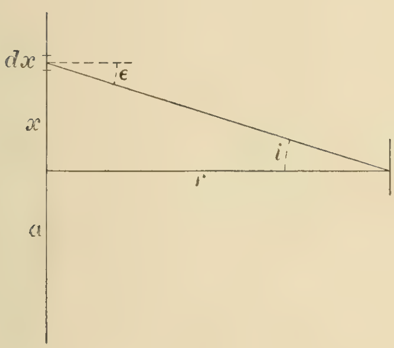


Fig. 3

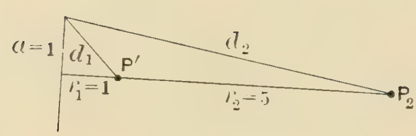


Fig. 4

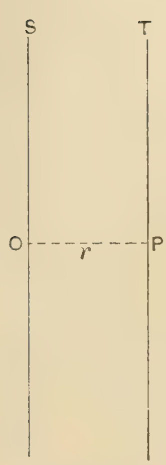


Fig. 5

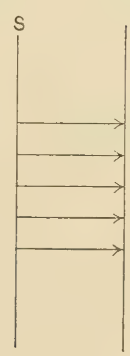


Fig. 6

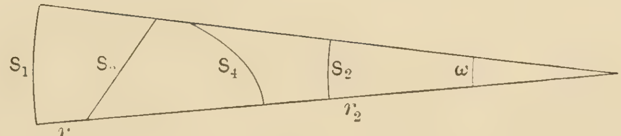


Fig. 7

4. UNIT DISC.

An elementary disc dS of brightness e gives an illumination at P, Fig. 1, equal to

$$E_p = \frac{edS \cos \epsilon}{r^2} = \frac{Q \cos \epsilon}{r^2}.$$

Where $Q = edS$ is the *quantity of light* on the disc.
Integrating this over the hemisphere within which the whole radiation is confined, we have the total flux,

$$F = Q \int_o^{\frac{\pi}{2}} \frac{2\pi r^2 \sin \epsilon \cos \epsilon \, d\epsilon}{r^2}$$

$$= \Big[\pi Q \sin^2 \epsilon\Big]_o^{\frac{\pi}{2}} = \pi Q \quad \pi I_1 \qquad (5)$$

Thus, the total luminous flux F from a small plane disc is π times the quantity of light Q on the disc, and also π times the maximum intensity I_1, normal to the disc. The average intensity throughout the hemisphere is one-half of the maximum intensity (πI_1 divided by 2π) and the mean spherical intensity is one-fourth I_1. Thus we have, since $I_s = \frac{1}{4} I_1$.

$$F = \pi I_1 = 4\pi I_s. \qquad (6)$$

That is, the total flux F is 4π times the mean spherical intensity as with a point source or uniform sphere. In the case of the disc, the spherical reduction factor is hence $\frac{1}{4}$. We must therefore carefully distinguish in the various forms of light sources between the mean spherical intensity I_s, the maximum intensity I_1, and the intensity in some particular direction I.

5. EXTENDED SOURCE. CIRCULAR DISC.

Let dS be an element of a plane radiating surface of *specific light intensity* (or brightness) e, defined by the equation

$$I = edS.$$

That is, the intensity I is equal to the product of e into the small surface dS. Thus, e is the value of the intensity I when the surface is unity, and is the quantity of light per unit of area measured in candles. Thus the intensity I would be measured

by comparing it experimentally with a standard light source, and it is equal to the intensity of a point source or unit sphere which produces the same illumination on a given test screen (of a photometer). Thus, while we *define* the intensity of a light source as the luminous flux per unit solid angle, we *determine* it by comparison with a concrete standard by means of the illumination produced on a test screen at a convenient distance, using a photometer and employing the law of inverse squares.

In Fig. 2 the illumination at P_1 in the normal to dS is

$$E_1 = \frac{e dS}{r^2},$$

while the illumination at P_2, the angles of emergence and incidence being ϵ and i respectively is

$$E_2 = \frac{e dS \cos \epsilon \cos i}{r^2}. \tag{7}$$

The cosine law is assumed to hold exactly for both surfaces.

To calculate the illumination due to a circular disc of brightness (*i. e.* specific light intensity) e and radius a on a small plane area P, normal to the axis of the disc at distance r we integrate the effect of each elementary circular ring of the disc. Thus, in equation (7), putting $dS = 2\pi x dx$,

$$E = e \int_0^a \frac{2\pi x dx \cos \epsilon \cos i}{(r^2 + x^2)}.$$

$$\text{Since } \cos \epsilon = \cos i = \frac{r}{\sqrt{r^2 + x^2}}$$

$$E = \pi e \int_0^a \frac{2x dx \cdot r^2}{(r^2 + x^2)^2} \tag{8'}$$

$$= \pi e \left[-\frac{r^2}{r^2 + x^2} \right]_0^a = \pi e \left[1 - \frac{r^2}{r^2 + a^2} \right]$$

$$\text{or, } E = \frac{\pi e a^2}{r^2 + a^2} = \frac{eS}{r^2 + a^2} = \frac{Q}{r^2 + a^2}, \tag{8}$$

where Q is the product of the surface of the disc into the specific intensity e, and is the total quantity of light upon the disc meas-

ured in candles. If the disc were very small Q would be the same as the intensity I of the source; but for an extended source we must distinguish between the equivalent *intensity* I and the surface integral of the *specific intensity,* which is Q. The latter we have called the quantity of light upon the disc; it is proportional to the total luminous flux F coming from the extended source, and is equal to F/π, equation (5). Q and F really measure the same thing, except that Q is located on the source and is measured in candles, while F is located in the surrounding space and is measured in lumens; their ratio is constant as $F = \pi Q$ always.[1]

In the case of the disc above mentioned, the illumination E on a small plane normal to the axis is proportional to the total quantity of light Q on the extended source (the circular disc) and inversely proportional to the square of the distance *d* from P_1 to the *edge of disc.* This holds true for all distances *r* from zero to infinity. Thus *the law of inverse squares holds generally for* the illumination along its axis due to a *circular disc of any size,* but the distance is measured, not to the center of the disc, *but to the edge.*

Thus we have

$$E = \frac{I}{r^2} \text{ for a point source or a unit disc,}^{2}$$

$$\text{and } E = \frac{Q}{d^2} \text{ for an extended disc.} \qquad (8a)$$

[1] The total quantity of electricity on a disc of area S is equal to the integral of the surface density σ over the area. Thus

$$Q = \int \sigma d S$$
$$= \sigma S \text{ when } \sigma \text{ is uniform.}$$

The brightness or specific light intensity e of a source corresponds to the surface density of electricity σ, and the total quantity of light over a surface is, in the same way, the surface integral of e. Thus

$$Q = \int e d S$$
$$= eS \text{ when } e \text{ is uniform over the area S.}$$

In the case of a sphere, the surface $S = 4\pi a^2$. Therefore, for the spherical source $Q = 4\pi a^2 e$, whereas the intensity $I = \pi a^2 e$. That is, the intensity I of a spherical source is one-fourth of Q, and is equal to the light on a disc of radius a and brightness e. That is, the intensity of the sphere is equivalent to that of a disc of the same diameter, and the same brightness, for points at a great distance.

[2] By unit disc or unit sphere is meant a disc or sphere whose linear dimensions are negligible in comparison with the distance from source to receiver.

To illustrate the rate of variation of the illumination with the distance, let $a = 1$, $r_1 = 1$, $r_2 = 5$.

In the first case for the point P_1, $E_1 = \frac{Q}{d_1^2} = \frac{\pi e}{2}$.

In the second case for the point P_2, $E_2 = \frac{Q}{d_2^2} = \frac{\pi e}{26}$.

Thus in the first case the distance is 5 times less and the illumination is 13 times more instead of 25 times more, as it would be if the light Q were all concentrated at the center of the disc. If $r = 0$, the illumination is πe or twice as much as at P_1, and not infinite as it would be at zero distance from a point source.

This theorem is useful in measuring the radiation from walls, as the radiating area may be quite large and the photometer relatively near.

6. INFINITE PLANE.

The radiation from an infinite plane S upon a unit area of a parallel plane T is found by integrating equation (8′) to infinity. Thus

$$E = \pi e \int_0^\infty \frac{2x\,dx . r^2}{(r^2 + x^2)^2} = \pi e \left[\frac{-r^2}{r^2 + x^2} \right]_0^\infty = \pi e. \qquad (9)$$

Thus the flux density or *illumination* at any point P on the T plane is π times the brightness or specific light intensity e on the radiating plane S, and is independent of the distance r.

From each unit of area of S having a specific light intensity e, the total flux is πe, as shown in (5) above. The resultant flux at all points is the same as though the total flux πe from each unit of area of S was confined to a cylindrical tube of unit area perpendicular to S, in which case the flux density would of course be constant at all sections, that is at all distances.

7. INFINITE CYLINDER.

In a similar manner we may consider the flux from an infinite circular cylinder of uniform specific intensity e, and radius a.

The flux coming from unit length of the cylinder is πe times the area. Hence $F = 2\pi^2 ae$; whereas the flux falling on the

inner surface of a concentric cylinder of radius r, is E times the area, E being the illumination. Hence, for a unit of length of the cylinder $F = 2\pi r E$. Therefore,

$$E = \frac{\pi a e}{r} = \frac{1}{2}\frac{Q}{r}. \tag{10}$$

Thus the illumination due to an infinite cylinder varies *inversely as the distance.* This is intermediate between the case of the point source, for which E is inversely as r^2, and the infinite plane, where E is independent of the distance; that is, proportional to r^0.

The quantity Q for the luminous cylinder is e times the surface. Therefore the *quantity per unit of length* is

$$Q_1 = 2\pi a e \tag{11}$$

The total luminous flux F, as stated above, is $2\pi^2 ae$. Hence the total flux per unit of length F_1, is π times the quantity or

$$F_1 = \pi Q_1.$$

or, for any portion (or the whole) of an infinite cylinder of uniform specific intensity, the total flux is π times the quantity; that is,

$$F = \pi Q \tag{12}$$

as shown above for a circular disc.

8. UNIT LENGTH OF CYLINDER.

Suppose a light source in the form of a very long cylinder of radius a and uniform specific intensity e. It is desired to determine experimentally its total luminous flux F. Suppose one has measured by means of a photometer the equivalent intensity I_1 of unit length of the cylinder, (screening the photometer from all but a short section of the cylinder): we are to calculate the total flux F from I_1. The unit length of cylinder will produce the same illumination at a distance as a rectangular plane of breadth $2a$ and height unity of specific intensity e equal to that of the surface of the cylinder. Hence the equivalent intensity I_1 is equal to $2ae$ and the illumination produced on a photometer screen at distance r is

$$E = \frac{2ae}{r^2} = \frac{I_1}{r^2}.$$

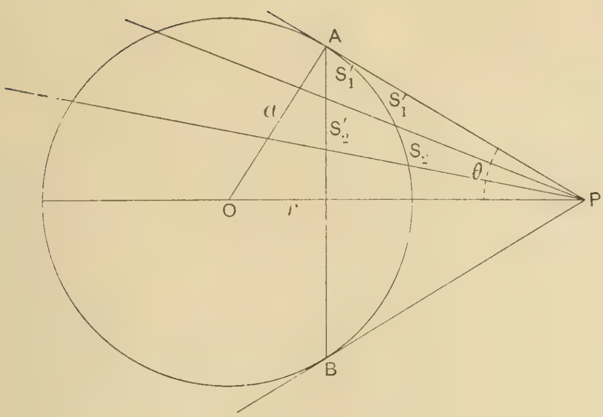


Fig. 8

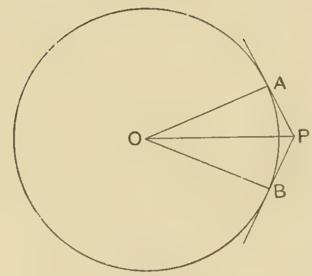


Fig. 9

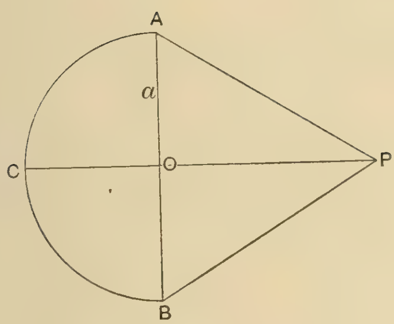


Fig.10

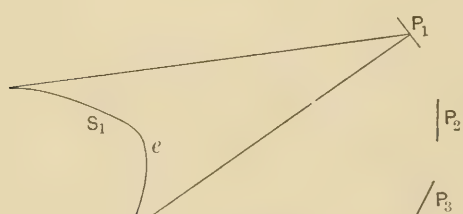


Fig.11

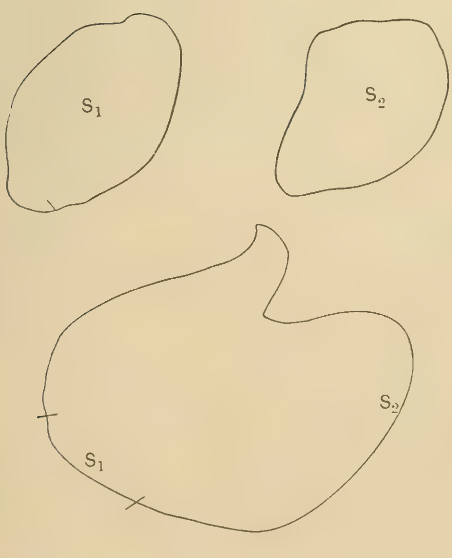


Fig.12

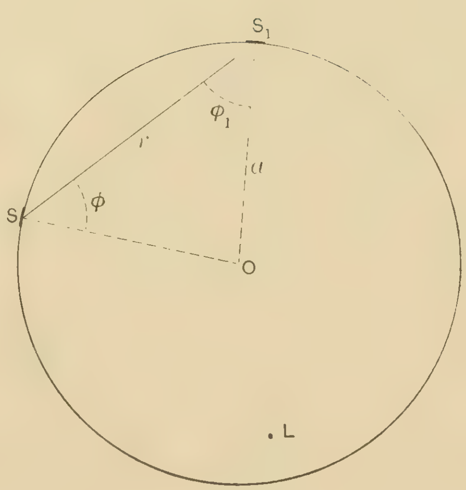


Fig. 13

The quantity of light on the cylinder per unit of length is e times the surface or $2\pi ae$; and the total flux F_1 is π times the quantity.

Thus we have

$$F_1 = 2\pi^2 ae$$
$$I_1 = 2ae$$
$$\therefore \quad F_1 = \pi^2 I_1 \qquad (1.)$$

Thus to obtain the total luminous flux F_1 from the measured value of the equivalent intensity of a unit of length of the luminous cylinder we multiply this intensity I_1 by π^2, instead of multiplying by 4π as in the case of a sphere.

The spherical reduction factor of a short cylinder (the convex surface only being luminous) is therefore $\pi^2/4\pi = \pi/4 = 0.785$. This would be nearly true for an incandescent lamp having a single, straight filament. The value for a hairpin filament would be only slightly larger.

If the cylinder is quite long, we should then get the total flux F by multiplying F_1 by the length of the cylinder. This demonstration is of course based on the assumption that the cosine law holds for the cylinder. If the source is a long tube, like the Moore light, the result would be subject to any modification dependent on its departure from the cosine law.

Thus while the total flux F is always π times the quantity Q of the source, it is not always 4π times the intensity. It is 4π times the intensity I for a point source or sphere, $\pi^2 L$ times the equivalent intensity I_1 (measured at a relatively great distance) of unit length of a long cylinder, L being the length, and πS times the equivalent intensity I_1 of unit of area of a plane, S being the area of the plane.

It is, however, always 4π times the *mean spherical intensity* of the given source. The illumination produced by a short cylinder is approximately inversely proportional to the square of the distance. For all distances greater than five times the length, the departures are not greater than 0.2 per cent. in a particular case worked out by Hyde; the diameter of the cylinder in this case was one-tenth the length. The exact expression for the illumination due to a finite cylinder is not simple, and the calculation tedious.

9. CASE OF LARGE SPHERE.

If a surface S_1 (suppose a portion of a spherical surface of radius r_1) has a specific light intensity (brightness) e and subtends a small solid angle ω, the illumination which it produces at P is

$$E = \frac{eS_1}{r_1^2} = \frac{e\omega r_1^2}{r_1^2} = e\omega. \tag{14}$$

A second surface S_2 of the same specific intensity will produce the same illumination at P provided it subtends the same angle ω. A third surface, S_3, at any angle will also produce the same illumination at P if it has the same specific intensity e and subtends the same solid angle ω. For the radiation of each element dS_3 is

$$\frac{edS_3}{r_3^2} \cos \epsilon = \frac{e\omega r_3^2}{r_3^2} = e\omega$$

as before. So also with the curved surface S_4. In every case the greater distance from P or the inclination of the angular position is compensated by the greater area included within the given solid angle.

Let us calculate the illumination at P due to a large luminous sphere of radius a and specific intensity e, r being the distance from P to the center of the sphere. Let the solid angle APB subtended at P by the sphere be subdivided into a large number of elementary solid angles. Each of the latter encloses an area, as S_1, on the surface of the sphere, and also a corresponding area S_1', on the circular disc AB. As we have just seen, the illumination produced at P by each spherical area S_1, S_2, etc., is exactly the same as that produced by the corresponding plane areas S_1', S_2', etc., of the disc, if the specific light intensity e is the same for the disc as for the sphere. Therefore, the illumination at P due to the entire sphere is the same as that due to the disc AB, and we can calculate the latter by formula (8a). That is,

$$E = \frac{Q}{d^2},$$

where Q is the quantity of light on the disc and d is the distance

AP from the point P to the edge of the disc. Q is equal to e times the area of the disc, or

$$Q = \pi(a \cos \theta)^2 \cdot e$$

$$d = r \cos \theta$$

$$\therefore E = \frac{Q}{d^2} = \frac{\pi a^2 e}{r^2}$$

$$= \frac{1}{4} \frac{Q_s}{r^2} = \frac{I_s}{r^2}, \qquad (15)$$

where Q_s is the quantity of light on the sphere $= 4\pi a^2 e$ and is constant for all distances, and I_s is the intensity of the equivalent point source. Therefore, the illumination produced by a *sphere of any size* is inversely proportional to the square of the distance measured *from its center,* and is equal to the intensity of a point source (or unit sphere) having the same total amount of light divided by the square of the distance. In other words, the inverse square law holds just as rigorously for large spheres as for points, (always, of course, assuming the cosine law to hold for the spherical surfaces, and the specific intensity e to be uniform over the sphere). When P comes very near to the surface the area AB of the sphere available for illuminating P is very small, but the distance is just enough less to counterbalance When P comes up to the surface, $r = a$, and

$$E = \pi e$$

the same as for an infinite plane, to which the sphere is equivalent when the distance from the surface is reduced to zero.

The same result is reached more simply as follows:

A luminous sphere of radius a and uniform specific light intensity e gives off a total flux $F = 4\pi a^2 \times \pi e = 4\pi^2 a^2 e$. This produces an illumination on the inner surface of any concentric sphere, which by symmetry will be uniform over any spherical surface and $F = 4\pi r^2 E$.

$$\therefore E = \frac{\pi a^2 e}{r^2} = \frac{I}{r^2}.$$

Therefore, *the illumination produced by a sphere of uniform specific intensity e is inversely proportional to the square of the distance from the center for all distances, from the surface of the sphere to infinity.*

10. RECIPROCAL RELATIONS.

From what precedes we see that the illumination at any point P due to the hollow hemisphere ACB is the same as that due to the circular disc AOB. The latter is

$$E = \frac{\pi a^2 e}{AP^2}. \tag{16}$$

When OP is reduced to zero, the illumination due to the disc is πe, and hence the illumination at O on an elementary plane area in the diametrical plane is π times the specific intensity e of the surface of the sphere. We have already seen that the total flux from a unit of surface of intensity e is πe. Hence the total flux through unit area S at O, due to the hemisphere, is equal to the total flux through the hemisphere due to the luminous unit area S, the specific intensity e being the same in each case.

This is a particular case of a more general proposition, namely; *the flux due to any surface* S *passing through an element* dS *is equal to the flux due to the latter passing through the former,* the specific intensity being the same in each case.

As shown above, the illumination E at P_1 due to S_1, is equal to $e\omega$ where e is the specific intensity of S_1 and ω is the solid angle subtended at P_1 by S_1, this is independent of the shape of S_1 or its distance from P_1. The flux F passing through dS at P_1 is therefore

$$F = \int e\,d\omega\,dS \cos\theta, \text{ over the area of } S_1. \quad \text{Or}$$

$$F = e\,dS \int d\omega \cos\theta. \tag{17}$$

Similarly, the flux due to dS at P_1 passing through S_1 is

$$\begin{aligned} F &= \int e\,dS \cos\theta \, d\omega \\ &= e\,dS \int \cos\theta \, d\omega. \end{aligned}$$

In the integration, every element $d\omega$ of the solid angle is to be multiplied by the cosine of the angle it makes with the normal to the area dS.

As the same theorem holds for the elementary areas P_2 and P_3, etc., it holds for their sum, and hence for a finite surface S_2.

Hence we see generally that *the luminous flux due to a surface* S_1 *passing through* S_2 *is equal to the luminous flux due to* S_2 *passing through Sr*, the specific intensities e being the same in each case. This is analogous to the theorem that the magnetic flux due to a magnetic shell S_1 which passed through a second shell S_2, is equal to that part of the magnetic flux of S_2 which passes through S_1, the strength of the shells being supposed the same. Or, again, the number of lines of force due to unit current in an electric circuit S_1 passing through S_2 is equal to the number of lines of force due to unit current in S_2 passing through S_1. It follows from the above that in any closed surface of uniform specific intensity e, the flux passing out from any portion S_1 is equal to that received from the remainder of the surface, S_2.

II. HOLLOW SPHERE.

Suppose a hollow sphere of uniform surface having a coefficient of diffuse reflection m.

$$1 - m = \text{absorption.}$$

$$\text{Let } E = \text{illumination at S.}$$

$$E' = mE \quad \text{radiation from S.}$$

$$e = \frac{mE}{\pi} = \text{specific intensity or brightness of S.}$$

The flux falling on S_1 due to S is,

$$S_1 dE_1 = \frac{eSS_1 \cos^2\phi}{r^2} = \frac{mE}{\pi}\,\frac{SS_1\cos^2\phi}{r^2}. \qquad (18)$$

$$\left.\begin{aligned} \text{But } r &= 2a\cos\phi \\ r^2 &= 4a^2\cos^2\phi \\ \frac{\cos^2\phi}{r^2} &= \frac{1}{4a^2} \end{aligned}\right\} \quad \therefore dE_1 = \frac{mE}{\pi}\,\frac{S}{4a^2},$$

and this is the same for every element of the sphere. Hence *every element* illuminates all other elements equally. Therefore, the *indirect* illumination of the sphere must be the same everywhere, no matter how unequal the direct illumination may be. That is, a light at L illuminates the sphere unequally, directly. But that part of the total illumination due to diffuse reflection is, notwithstanding, equal everywhere.

A light of mean spherical intensity I sends out $4\pi I$ lumens.

Of this there is reflected, 1st, $4\pi m I$ lumens.
Of this there is reflected, 2d, $4\pi m^2 I$ lumens.
Of this there is reflected, 3d, $4\pi m^3 I$ lumens.

Therefore, total amount of flux reflected is $4\pi I m\ [1+m+m^2+m^3+\ldots] = 4\pi I \dfrac{m}{1-m} = F_2$.

Hence, the secondary illumination, everywhere equal on the surface of the sphere, is

$$E_2 = \frac{F_2}{4\pi a^2} = \frac{mI}{a^2(1-m)} \tag{19}$$

Thus, the indirect illumination is proportional to I, and the lamp of intensity I may be anywhere in the sphere. It is equal to $\dfrac{m}{1-m}$ of what the direct illumination would be if the source were placed at the centre of the sphere.

For example, let a 16 candle-power lamp be placed within a sphere having a radius of one meter, and a coefficient of diffuse reflection of 0.8.

Then $I = 16$.
$a = 1$ meter.
$m = 0.8$.
$E_2 = \dfrac{0.8}{0.2} \times \dfrac{16}{1} = 64$ meter candles.
$E_1 = \dfrac{I}{a^2} = 16$ meter candles, if lamp is in the center.
$E = E_1 + E_2 = 80$.

Thus, the total illumination is five times what it would be if the walls were perfectly black. We can put this in another way: Of the total illumination of 80 meter candles, 20 per cent. is absorbed by the walls. Therefore, the lamps or source must supply only one-fifth of the total illumination, just enough to make good the constant loss.

Thus, the source is analogous to an exciter of electric waves that must supply just enough energy to make good the friction or resistance losses in the circuit.

12. LUMINOUS FLUX WITHIN AN ENCLOSURE.

If the inner surface of the hollow sphere has a brightness e, and a specific radiation $E' = \pi e$, a unit disc at the center of the sphere will receive an illumination $E = \pi e$. The same will be true wherever the unit disc is placed within the sphere, and whatever the orientation of the disc. That is, the flux falling on the disc will be everywhere the same. The flux density within the hollow sphere is therefore everywhere uniform and equal to πe. The flux from a point source is thought of as in straight lines, and a disc can be placed normal to the direction of the flux. But within the sphere the flux has a uniform value, but no resultant direction.

Within a cube or enclosure of any shape, of which the walls have a uniform brightness e or uniform specific radiation E' the same condition obtains as in the sphere; namely, the luminous flux is everywhere the same, and a small area will have the same illumination no matter where it is placed or how it is oriented. This is seen by dividing up the space about any point P into elementary solid angles. The illumination due to the surface subtending an angle ω is independent of the distance from P, and hence it will be πe for the total angle 2π on either side of the surface at P, no matter where the surface is placed.

The same is true therefore for the space between two infinite planes of brightness e. The illumination is πe on a small plane at P_1, P_2 or P_3, anywhere between the two radiating planes S and T no matter how they may be placed. Evidently we cannot think of the flux as normal to the planes, as with the lines of force due to electrostatic charges on the planes S and T. The luminous flux normal to P_3 is the same as normal to P_1. On the other hand, the electric force normal to P_3 would be zero.

These theorems have a practical application in the lighting of rooms.

13. SUMMARY OF PHOTOMETRIC RELATIONS.

The preceding discussion has shown the necessity for distinguishing several different photometric quantities which are sometimes confused. One writer has advocated the use of the fewest possible names, and has tried to show that *intensity, flux* and *flux*

density are sufficient. In order to fix our ideas more clearly it will be advantageous now to state as concisely as possible the definitions of the several quantities and distinctions between them.

Luminous flux, or *light* as the term is used in photometry, is the usual physical stimulus which excites vision. It is propagated by means of the vibratory motion in the ether, and the frequency of the vibrations, or the combination of frequencies present in any given case, determines the color. The total quantity of flux F flowing away from a monochromatic luminous source is

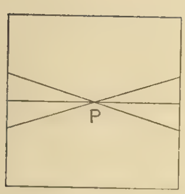


Fig.14

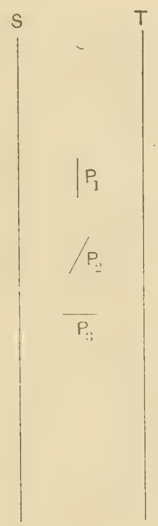


Fig.15

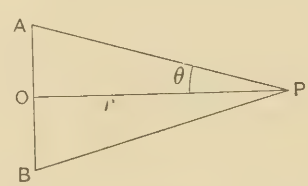


Fig.16

proportional to the total radiant energy, and to a stimulus coefficient, the latter being the luminous efficiency K_λ for the particular frequency or wave length of the given radiation. Thus the equations

$$F = K_\lambda W$$

$$K_\lambda = \frac{F_\lambda}{W_\lambda}$$

express the luminous flux as the power W multiplied by the luminous efficiency K_λ, and if flux is expressed in *lumens* and the power in *watts,* the luminous efficiency is the number of lumens per watt of radiation of the wave length λ. For white or chromatic light, K will have a value depending on the distri-

bution of the energy in the spectrum. It is a maximum in the yellow green region and falls off rapidly in either direction, reaching zero at the limits of the visible spectrum. The luminous efficiency of most light sources is greatly reduced by the amount of radiation outside the visible spectrum, chiefly of longer wave length than that of visible radiation, and the total efficiency of such a source,

$$K = \frac{F}{W}$$

is the quotient of the total luminous flux divided by the total radiant power.

For the purposes of definition and of expressing the mathematical relations involved in photometry, it is permissible to confine ourselves to monochromatic light, and to consider K a constant, although it does in fact vary somewhat with the magnitude of the flux density. We also assume that all surfaces are perfectly diffusing and obey the cosine law, and that there is no absorption in the atmosphere.

The intensity of a point source or uniform luminous sphere is measured by the luminous flux flowing through a unit solid angle whose apex is the given point or center of the given sphere. Thus from a source of intensity I, light is flowing away at a rate of I lumens per unit solid angle or a total of $4\pi I$ lumens for the point source or uniform sphere. If the source is not uniform, and light is flowing away at unequal rates in different directions, the intensity I in any direction is equal to the flux dF in an elementary solid angle $d\omega$ taken in the given direction. Thus

$$I = \frac{dF}{d\omega}$$

is a general expression applying to all point sources whether radiating equally or unequally in different directions. If the unsymmetrical source is extended, as for example an incandescent lamp or a diffusing globe, the same holds true if the distance at which the measurements are made are sufficiently great so that the distribution of light is practically the same as from an unsymmetrical point source. For less destances than this, the intensity is not a constant in a given direction, but varies with r.

In this case the equivalent intensity at any point is equal to that of a point source which gives the same flux density, or *lumens* per sq. cm., at the point that the given source does. The mean spherical intensity I_s is the average value of the intensity, and is equal to the total flux F divided by 4π.

The total flux from a given extended source is therefore a constant independent of distance, as is also the mean spherical intensity I_s. The intensity I in a particular direction, however, in the case of extended sources other than spheres varies with the distance, but at relatively great distances the variation is inappreciable.

Thus the luminous flux is the fundamental quantity. But while we *define* I as the flux per unit solid angle, or *rate of flux with respect to solid angle,* we *determine* I by comparison with a concrete standard. Thus photometric standards are really standards of light flux, their values being expressed in *candles.*

If f is the spherical reduction factor with respect to any particular direction, and I is the intensity of a source in that direction,

$$I_s = fI$$

For a unit disc, that is a small circular disc of uniform brightness, the total flux is π times the normal intensity I_1, whereas the mean spherical reduction factor with respect to the normal is ¼. Hence, the total flux is

$$\begin{aligned} F &= \pi I_1 \\ &= 4\pi I_s, \text{ as for a sphere.} \end{aligned}$$

In general, for any light source, $F_s = 4\pi I_s = 4\pi f I$, but for extended sources other than spheres, the value of f as well as I varies with the distance from the source for points relatively near the source.

The *specific flux* or *flux density* is the luminous flux per unit of area, or lumens per square centimeter. When the flux falls upon a material surface, we call the specific flux the *illumination,* E. When we speak of the flux coming *from* a surface, whether it be a self-luminous source at high temperature, or a reflecting or radiating surface at low temperature, we call the specific flux the specific radiation, or simply the *radiation,* E′.

Thus the illumination E is

$$E = \frac{F_i}{S} = \frac{dF_i}{dS} = \frac{I}{r^2}.$$

The radiation E′ is

$$E' = \frac{F_e}{S} = \frac{dF_e}{dS}.$$

F_i is the incident flux, F_e is the emitted or radiated flux. If m is the coefficient of diffuse reflection or transmission, $(1 - m)$ being the absorption,

$$F_e = mF_i$$
$$E' = mE,$$

where the radiation consists in the diffuse reflection or transmission of a portion of the incident flux or illumination.

The radiation or illumination when large may be expressed in lumens per sq. cm.; when small in milli-lumens per sq. cm. The milli-lumen per sq. cm. is nearly equivalent to the foot-candle.

1 lumen per sq. cm. = 10,000 lumens per sq. meter.
= 10,000 meter candles.
1 milli-lumen per sq. cm. = 10 meter candles = 10 lux.
= $\frac{1}{1.0765}$ foot-candles.

Specific intensity e of a source is the intensity in candles per sq. cm. of area, taken normally. Thus

$$e = \frac{I}{S} = \frac{dI}{dS}.$$

Brightness, or *specific* light intensity, refers to the quantity of light per unit of area of a source, and is measured in candles per sq. cm. Brightness can refer equally to luminous sources of relatively high specific intensity or to reflecting and radiating sources of low intensities. The latter may be conveniently expressed in milli-lumens per sq. cm. Thus we may say a flame has a specific radiation of 10 lumens per sq. cm. or a brightness (specific intensity) of 0.8 candles per sq. cm.; and a wall has a specific radiation of 10 milli-lumens per sq. cm., or a brightness of 0.8 milli-candles per sq. cm. or of 8 candles per sq. meter.

The quantity Q is proportional to the total amount of light

emitted by the source, and is equal to the surface integral of the specific intensity e. Thus

$$Q = \int e dS.$$

The quantity for a small luminous circular disc of radius a and uniform specific intensity e is

$$Q = \pi a^2 e = I_1.$$

That is, the quantity is equal to the maximum intensity. In this case, the whole surface is equally effective in producing the illumination on the test screen by which the intensity I is measured. But for an extended disc, the quantity and the normal intensity, as we have seen above, are not the same. Thus, the quantity is e times the surface, or

$$Q = \pi a^2 e,$$

$$E_1 = \frac{Q}{a^2 + r^2} = \frac{I_1}{r^2},$$

$$\therefore \frac{I_1}{Q} = \frac{r^2}{a^2 + r^2} = \frac{r^2}{d^2} = \cos^2 \theta.$$

That is, the normal equivalent intensity of the disc with respect to the point P is Q times $\cos^2\theta$. When the distance is equal to the radius of the disc, the quantity Q is twice the normal intensity I_1.

The total luminous flux is $\pi e S$ or π times the quantity, and the mean hemispherical intensity is $\frac{Q}{2}$ or half the quantity.

In the case of a sphere of uniform specific intensity e the quantity is $\int e dS = 4\pi a^2 e$. The intensity $I = \pi a^2 e$. Hence the intensity is one-fourth the quantity. In other words, the total radiation from the sphere is four times as great as from a unit disc of the same normal intensity. The relation between quantity and intensity for a few simple cases are

For a unit disc $I_1 = Q$.

For an extended circular disc $I_1 = Q \cos^2 \theta = Q\frac{r^2}{d^2}$.

For a sphere $I = \frac{1}{4}Q$.

For a unit cylinder $I = \frac{1}{\pi}Q$.

The total luminous flux delivered in a given time, that is the time integral of the luminous flux, may be expressed in lumen seconds or lumen hours, according to circumstances. Thus, putting L for the *total lighting* in the time T

$$L = FT$$
$$= \int F dT, \text{ if F is variable.}$$

where F is in lumens and the time is expressed in the most convenient unit. The flash of a firefly may be expressed in lumen-seconds; the quantity of light per gram of an illuminant, or the total light given during the life of an incandescent lamps is better expressed in lumen-hours.

Since flux of light may also be expressed in spherical candles, $\left(\frac{1}{4\pi} \text{ times the lumens}\right)$ we may also express the time integral or total quantity of light in terms of spherical candles and hours. Thus

$$L = I_s T$$
$$= \int I dT, \text{ if the spherical candle-}$$

power is a variable with respect to T, the value of L being here given in candle-hours.

The photometric quantities employed in the preceding discussion are shown in Table I, together with the units in which are expressed and the equations of definition.

The symbol F has been employed for the flux (as originally proposed by Hospitalier) instead of Φ for the following reasons:

1. Φ is the only Greek letter in the series, and it is more consistent to use a Latin letter; F is the initial letter of the word flux.

2. The letter Φ is more or less unfamiliar to many illuminating engineers, and also to many printing offices, and it is often confused with the small letter ϕ which is used for an angle.

The symbol E′ is used for radiation instead of R (as proposed by Hospitalier) because it is so closely related to the illumination. Blondel and others proposed to employ the same letter E for illumination and radiation, but that gives rise to confusion.

TABLE I.

Photometric magnitude.	Symbol.	Unit.	Equation of definition.
1. Intensity of Light	I	Candle	$I = \frac{F}{\omega}$
2. Luminous Flux	F	Lumen	$F = I\omega = \frac{IS}{r^2} = ES = \pi Q$
3 Illumination	E	$\frac{\text{Lumens}}{cm^2}$ or $\frac{\text{milli-lumens}}{cm^2}$	$E = \frac{F_i}{S} = \frac{I}{r^2}$
4. Radiation	E′	Lux = meter-candle	$E' = \frac{F_e}{S} = \pi e = mE$
5. Brightness	e	$\frac{\text{Candles}}{cm^2}$	$e = \frac{I}{S \cos \epsilon}$
6. Quantity	Q	Candles	$Q = eS$
7. Lighting	L	Lumen-hours	$L = FT$

I, e, Q are expressed in candles. F, E, E′ are expressed in lumens. L is in lumens or spherical candles.
$E' = \pi e$. $F = \pi Q$. F_i = incident flux. F_e = emergent flux.
m = coefficient of diffuse reflection or transmission $(1 - m)$ = coefficient of absorption.

On the other hand, E′ gives sufficient distinction, and at the same time recalls their close connection. The letter e is used instead of i for the *specific intensity* or brightness because it has been used in France and Germany, and hence its use in the English language tends to uniformity. Quantity of light, Q is here used as the surface integral of e instead of the time integral of F. It is analogous to quantity of electricity in electrostatics, and is more properly employed in the sense here used than with the other meaning: The term *lighting* for *flux* times *time* is used in harmony with the usage in France and Germany.

III. PROBLEMS FOR ILLUSTRATION.

Problem 1.—A lamp of 200 candle-power (supposed uniform in all directions) is placed in the center of a spherical diffusing globe of 40 cm. diameter, the absorption of which is 30 per cent. Required, the intensity of the globe, its specific intensity, its specific radiation, the illumination on its inner surface, and the illumination it produces at a distance of 3 meters from the center of the globe.

The illumination on its inner surface is

$$E = \frac{I}{a^2} = \frac{200}{400} = 0.5$$

lumens per sq. cm., (formula 1). The radiation E′ is mE, where m is one minus the absorption; it is here 0.7. Therefore, the radiation is 0.35 lumens per sq. cm. The specific intensity e is $\frac{E'}{\pi}$ or 0.112 candles per sq. cm. The intensity I of the globe is $200 \times 0.7 = 140$ candles. The illumination E at a distance of 3 meters

$$E = \frac{140}{300^2} = 0.00156 \text{ lumens per sq. cm.}$$

$$= 1.56 \text{ milli-lumens per sq. cm.}$$

$$1.45 \text{ foot-candles.}$$

$$\text{or } E = \frac{140}{3^2} = 15.6 \text{ meter-candles.}$$

$$15.6 \text{ lux.}$$

Problem 2.—A circular area S, two meters in diameter, on the side of a wall is uniformly illuminated, E being 4 meter-candles.

A photometer placed one meter from the wall, perpendicular to the center of the illuminated area, measures the equivalent intensity I of the area S, and finds it to be 1 candle. What is the absorption coefficient of the wall?

The illumination E being 4 meter-candles, and the area S being π square meters, the flux F falling on the area S is 4π lumens. The measured intensity I at a distance $r = 1$ meter is 1 candle. Therefore, the quantity of light on the disc is

$$Q = I_1 \frac{d^2}{r^2} = 1 \times \frac{2}{1} = 2 \text{ candles.}$$

The total flux from the disc is π times the quantity Q. Therefore, the total flux coming from the area S is 2π lumens, whereas the flux falling upon it is 4π lumens. Therefore, the coefficient of absorption is ½ or 50 per cent.

Problem 3.—Suppose a room of 900 square meters total wall surface is to be so lighted that the walls shall have an average illumination of 10 lumens per square meter, the coefficient of absorption of the walls being 40 per cent on the average. How many lamps of 15 mean horizontal candle-power will be required?

Part of the illumination will be due to light reflected from the walls. The lamps must supply that which is absorbed. The flux to be supplied is therefore $F = 0.40 \times 900 \times 10 = 3{,}600$ lumens. If each lamp has a spherical radiation factor of 80 per cent., it will supply $4\pi \times 0.80 \times 15 = 150$ lumens, approximately. Hence, 24 lamps will be required.

(Examples 1 and 3 are borrowed from one of Blondel's papers.)

COLLECTION OF FORMULAS.

1. $E = \dfrac{I}{r^2}$ for point source, unit sphere of any size. $I = 4\pi a^2 e$, where a = radius of sphere and e = brightness of surface.

2. $E = \dfrac{\pi a^2 e}{r^2}$ for sphere of radius a.

   $= \pi e$ when $r = a$; that is, at surface of sphere, same as for an infinite plane.

3. $E = \frac{\pi a^2 e}{a^2 + r^2} = \frac{Q}{d^2}$ for disc of radius a, at distance r on axis.

d = distance of point on axis to edge of disc.

4. $E = \frac{\pi a e}{r}$ for infinite cylinder, e = brightness or specific light intensity. a = radius

$= \frac{Q_1}{2r}$, where Q_1 = quantity of light per unit of length

$= \pi e$ at surface.

$I_1 = \frac{2ae}{r^2}$ = intensity per unit of length.

5. $E = \pi e$ for infinite plane, *at all distances.*

6. $E = \frac{e dS \cos \epsilon}{r^2} = e d\omega$ for any small surface dS subtending a small angle $d\omega$ at any distance.

7. $E = \frac{2e}{r} \cos \epsilon$, for infinitely long, very narrow strip of e units of light per unit of length

$= \frac{2Q_1}{r}$.

8. $Q = \int e dS$ over sphere, cylinder, disc or other surface where e = normal intensity.

9. $F_s = \pi Q$, for sphere or other extended source.

10. $E = \frac{Q}{d^2} = \frac{I_o}{r^2} \therefore \frac{I_o}{Q} = \frac{r^2}{d^2} = \cos^2 \theta$, for a disc.

I_o = equivalent point source, Q = quantity of light over disc

$I = Q/4$ for a sphere.

DISCUSSION ON THE PRECEDING PAPERS.

E. L. Elliott:—Two points particularly impressed me in the beginning of the paper, one of them being the distinction between subjective and objective illumination. We speak of illumination as the amount of light falling upon a surface, and we also think of it, at least the layman very commonly thinks of it, as the light reflected from the surface, in other words, the appearance of the surface. We speak of the illumination of the walls of a room as the way they appear to the eye. Dr. Rosa cleared up this point in a manner that to me is new, and I think very acceptable. He considers the illumination as subjective, as actually the amount of light falling upon a surface, and radiation as the amount of illumination that is apparent, or light reflected from the surface, for certainly a surface reflecting light radiates light as much as if it were luminous.

The following definition of light is given on the third page of Dr. Rosa's paper: "Luminous flux, or *light* as we ordinarily say, is the physical stimulus which, applied to the retina, produces the sensation of light. It is equal to the radiant power multiplied by the stimulus coefficient." The point, it seems to me, is made very clear, at least it appeals to me as clearing up the question very admirably.

There are a number of ways of arriving at conceptions of the various photometric measurements, several of which have been proved at different times, in different papers presented before the Society. I think that this is the first time that the matter has been considered in parallel with electrical measurement—a fact that will certainly appeal to those who are familiar with these measurements.

V. R. Lansingh:—Dr. Rosa has given us in his paper the nomenclature used in considering the physical quantities of light. The other side of the subject, the physiological, he has not considered. I would simply like to call attention to two terms which, while they have not been standardized yet are of use. One I may term the efficiency of the eye; this may be defined roughly as the amount of illumination necessary to see clearly a given object when a light is shining in the eye, as

compared with the amount of illumination necessary to see this object when the light is not shining in the eye. This efficiency of the eye is of special value in the case of street lighting, where we have lights of high intensity shining in the eye; also in the case of interior illumination, where we have visible light sources.

The other term visual efficiency, and is the combined efficiency of the eye and the illumination as measured on the photometer or illuminometer. Thus, in the case of street lighting, it would be a combination of the efficiency of the eye, multiplied by the illumination, as measured on the illuminometer, *i.e.*, the ability to see. After all, when we reach the real basis of our illumination, what we want is the ability to see, so that it is necessary to take into account, not only the physical quantities which Dr. Rosa so well brought out, but also the effect on the eye; the combination of the two is what might be called visual efficiency.

C. H. Sharp:—The point which Mr. Lansingh has just brought up is most important. I recently had occasion, in speaking on this subject before the Engineers' Society of Western Pennsylvania, to call that quality the "physiological efficiency" of the installation. Referring back to the eye of the observer, the installation has a certain physiological efficiency. Take a case like this room, by rearranging the illumination and without producing any more foot-candles on this surface, we might very well increase the physiological efficiency. That would be obtained by removing glaring light from the eye.

E. B. Rosa:—Would not that simply be a matter of opening the iris a little wider to take in the illumination? If a bright light is shining in the eye, the pupil contracts, and therefore the window is smaller, and we can take in less of the objects which we attempt to see. To remove anything that is glaring, as I gather from the remarks made, means that we are permitting the eye to open and take in the illumination more freely, and therefore the total quantity may be correspondingly reduced.

V. R. Lansingh:—Replying to Dr. Rosa's point, Mr. Sweet has investigated this subject very carefully, and his conclusions are that the pupilary contraction has very little to do with the effect of glare in the eye. He defines glare in the eye about as

follows: We have the effect of glare when the regenerative powers or functions of the eye are insufficient to take care of the degenerative effects of the light stimulii; for example, we may be looking at an object with a light source in the field of vision; if the two are so close together that the stimulii from the bright light overlap that portion of the retina, where the stimulii are falling from the less bright part, then we have a glare, but if the bright light is so far removed, that the two images do not fall on the same part of the retina and the effect of the glare is nil. From the investigations of Mr. Sweet it was brought out that if a bright light is raised to an angle greater than 26 degrees from the line of direct vision, then there is enough separation of the two images on the retina of the eye so that the glaring effect is nil; that is, the stimulii from the bright light do not overlap that portion of the retina, where the stimulii of the less bright object fall.

C. H. Sharp:—If we look out of the window of a dark room on a moonlight night, objects outside can be seen clearly. Now, let us turn on light in the room, and that vision of the outside object is obliterated instantly. We know the iris does not act as quickly as that. Something else intervenes besides the closing or contracting of the eye, I think.

Dr. Rosa has brought to our attention to-night a new quantity, termed "quantity of light or surface integral of light," and he has shown how readily it adapts itself to mathematical discussions of this character.

On one page of the paper, mention is made of the spherical reduction factor of a short cylinder. If a short cylinder has a surface which obeys Lambert's law, its spherical reduction factor is 0.785. A well-known physicist and photometrist in England recently rediscovered this ancient relation, and immediately made the statement that on account of this relation the spherical reduction factor of all incandescent lamps could be taken for practical purposes as equal to about 0.785. That statement has been repeated over and over again in the technical photometric literature in England. Now, it is not correct. We have lamps in this country whose reduction factor is practically 1, the mean horizontal and the mean spherical candle-power being substantially equal. This is not practically

the same thing as 0.785. If we have a lamp with a narrow hairpin, the spherical reduction factor is about 0.785. In the case of the oval anchored filament the reduction factor is equal to 0.81, which varies considerably from 0.785. For a lamp with a coil in the filament, the reduction factor may run up to 0.85 or 0.88 instead of 0.785.

In this connection another curious fact occurs, that some lamps have a smaller factor than 0.785—the tantalum lamp, for instance, shows a reduction factor as low as 0.74, or even 0.7. This means nothing else than that it tries to agree with Lambert's cosine law and cannot do it. It is a smooth metallic surface, and the radiation at right angles to the surface is proportionally much greater than it is at oblique angles; consequently its reduction factor falls below the theoretical limit

Nearly one hundred and fifty years ago Lambert wrote a
set for surfaces which follow the cosine law.
book on photometry and the measurement of light and shade. Though originally written in Latin, the book has been translated into German. It is a perfect mine of geometrical relations and theories which are now coming to the front as being of some practical value in illuminating engineering. We have not really got very far beyond Lambert's mathematics in the study of the geometrical relations entering into light values.

E. B. Rosa:—The paragraph in the middle of page 492 reads, "For the purposes of definition and of expressing the mathematical relations involved in photometry, it is permissible to confine ourselves to monochromatic light, and to consider K a constant, although it does in fact vary somewhat with the magnitude of the flux density. We also assume that all surfaces are perfectly diffusing and obey the cosine law, and that there is no absorption in the atmosphere." Of course, the cosine law is not observed exactly, and varies with different substances, but mathematically we must assume something. If we do not assume that, we could not make any progress at all.

Dr. Sharp in his paper speaks of measuring the resistance of the filament of the lamp. I would like to say that lamps are very often sent to us to be standardized that are not seasoned properly, sometimes because the persons sending them have no way of telling whether they are seasoned, and sometimes be-

cause they do not realize that they should be seasoned. We formerly measured them before burning them, and then burned them a little while and measured them again to see if the light changed and so judged whether they were seasoned.

In our recent practice, for the last year, we have been measuring the current and voltage by means of accurately standardized potentiometers, and so can tell in ten minutes if the lamps are seasoned. We simply measure the current or the voltage with ten times the precision we formerly did in photometry, and if the resistance decreases, we know that they have not been properly seasoned, or if it increases considerably we know that they have burned too long. We then reject them or put them on racks and burn them for a time, and measure them again. When they have been brought to a point where the resistance does not change, we feel reasonably sure that they will remain constant.

In our best standards, we have been testing the possibility of a long life by burning the lamps for a considerable period and obtaining what is practically a life curve. We have some standards that have been burned for 200 hours after seasoning to see how much the candle-power drops; in other words to see how good they would have been if used as standards long enough to burn so much. Suppose a group of lamps were used a hundred years as reference standards, and they are not burned more than an hour or two in the course of each year, how good would they be at the end of one hundred years; and what are the possibilities of maintaining the unit of light by means of carefully prepared incandescent lamps? We have burned lamps at constant watts, (that is, as the resistance changes, the voltage is changed, so that the rate of supply of energies is constant) the decrease in candle-power in one hundred hours amounting to only a few hundredths of a candle. In other words, the lamps could have been used as standards for one hundred years, barring accidents, and still be very good standards.

A paper presented at a meeting of the New England Section of the Illuminating Engineering Society, Boston, Mass., June, 13, 1910.

SOME MATTERS PERTAINING TO ILLUMINATING ENGINEERING.

BY J. S. CODMAN.

In the paper which I gave before the New England Section last year[1] I had in view the object of impressing upon those present the value of the "flux-of-light" method of calculating illumination and also the value of the term "lumen" as the unit of light flux. I did this because I believed that both the term lumen and the "flux-of-light" method were going to be used a great deal more extensively in the future. During the last year, the use of the flux-of-light method has certainly become more general, and if you will refer to the recent bulletins of the incandescent lamp manufacturers you will find that the number of lumens generated by a lamp is included with other data.

A word or two about the term "lumen," to be sure that we understand what it means. The easiest way, I think, to define it, at the present time, is by means of the term "foot-candle." Four or five years ago this term also was comparatively unknown, but to-day I think we all have a fairly clear idea of what "foot-candle" means and know that it is the unit of illumination. The easiest way, perhaps, to define a lumen is to state that it is the flux-of-light required on a surface of one square foot to give that surface an illumination of one foot-candle. There are other ways of defining the lumen, but I think this is the simplest. Looking at the matter in another way, we can say that a surface with an area of one square foot and receiving one lumen of light-flux has an illumination of one foot-candle, or one lumen per square foot. This last statement shows us that we can express illumination in terms of lumens per square foot instead of in foot-candles if we wish. In many ways this method of expressing it gives a clearer idea of what illumination is.

The diagram Fig. 1, is frequently used to demonstrate the law of inverse squares. By means of the flux-of-light method we

[1] TRANSACTIONS of I. E. S., April, 1909.

can also explain the law of inverse squares with this same diagram, which is supposed to represent the flux of light coming from a point light source, and falling on surfaces at different distances. If we suppose that this flux of light is, for example, 9 lumens, and that the area of the nearest surface is one square foot, we see that the illumination of this surface must be 9 lumens per square foot, or 9 foot-candles. The next surface

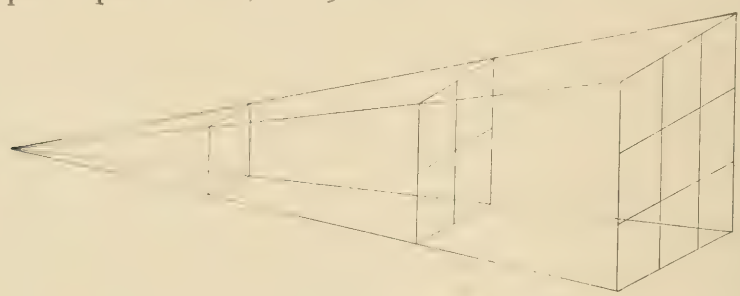


Fig. 1.

is twice as far away from the light source, but it still intercepts the 9 lumens of flux. Its area, however, is four times as great as the area of the nearest surface, and its illumination is 9 lumens of flux received, divided by its area, 4 square feet, and is consequently 2¼ foot-candles or 2¼ lumens per square foot. You will see, since the illumination of the nearest surfaces is 9 foot-candles and of the second 2¼, that the illumination of the second surface is one-fourth that of the first surface while the distance is twice as great; in other words, the illumination is inversely proportional to the square of the distance. Finally on the last surface we have 9 squares covered by the flux; that is, we have 9 square feet receiving 9 lumens which gives us one foot-candle.

Those who are familiar with the law of inverse squares sometimes feel that if a light source is raised high above the plane which it is illuminating, the illumination will necessarily fall. This is undoubtedly true if no change be made in the equipment of the light source. Suppose, for example, that we have a lamp at the point P in the diagram, Fig. 2, and underneath, to be illuminated, a circular surface of which the diameter is A B; that the flux from the lamp is passing out through the angle A P B represented here and that this flux is entirely intercepted by the surface as shown. We then have a certain definite illumination which is the number of lumens produced through this angle.

divided by the area of the surface. Suppose now we raise the light source to a point P′ without making any other change. The flux, of course, goes through the same angle, and evidently a large portion of it never reaches the surface at all. By equipping the lamp, however, with the proper reflector, we

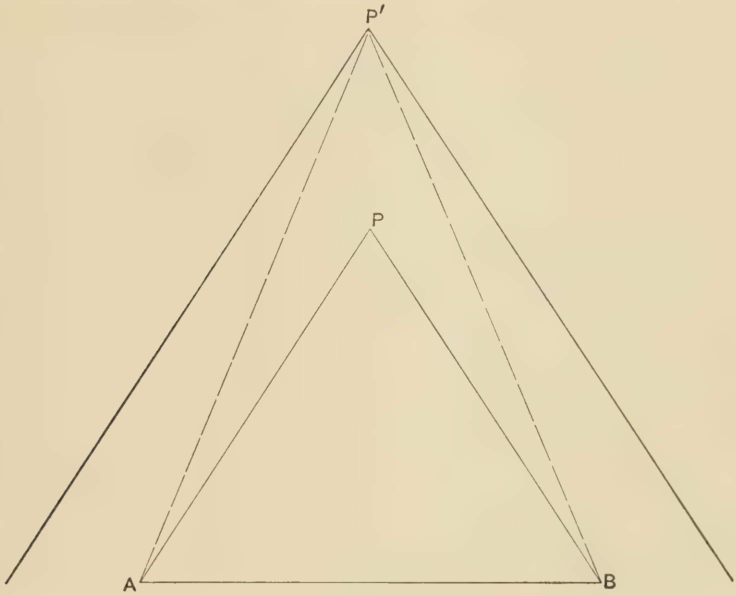


Fig. 2.

can crowd the flux into a smaller angle and maintain the same illumination on the surface. It is assumed in the diagram that the flux has been contracted by means of some reflector into the angle indicated by the dotted lines, and since there is now the same flux on the surface as before, the illumination must be the same in spite of the fact that we have raised the lamp. It is perfectly possible, if proper reflectors are used, to put the light source very high above the surface to be illuminated. It is simply a question of squeezing the flux into a narrow angle rather than allowing it to escape through a wide angle.

Table I, is intended to give an idea of the effective flux of

TABLE I.

Source of light	Flux of Light in lumens			Per cent. increase over bare lamps		
	0-60°	0-30°	0-10°	0-60°	0-30°	0-10°
Bare 100-watt Mazda	136	25	2	..	..	..
Extensive reflector	300	69	6	121	176	200
Intensive reflector	325	103	12	139	312	500
Focusing reflector	374	172	25	175	590	1150
Concentrating reflector	388	219	56	185	780	2700

different types of reflectors, and to show how the flux can be crowded into a small angle or zone. With a bare 100-watt Mazda lamp, we find the flux through the zone determined by the angles 0 and 10 degrees with the vertical is only 2 lumens; by 0 and 30 degrees is 25; by 0 and 60 degrees is 136. If we compare this with the same lamp equipped with different reflectors, we shall see very clearly why reflectors are so valuable.

Consider first the flux between 0 and 60 degrees. The bare lamp gives 136 lumens. If we look at the figures for this lamp equipped with four different types of reflectors, we find the lumens through the zone between 0 and 60 degrees run from 300 to 388, an increase of from 121 to 185 per cent. With still smaller zones the percentage gain with reflectors is even greater. Through a zone determined by the angles 0 and 10 degrees with the vertical, the bare lamp gives only 2 lumens; with the concentrating reflector it gives 56 lumens, an increase of 2,700 per cent. I think this shows plainly why concentrating reflectors are so effective.

But we must not be led by this table into the error of assuming that because the concentrating type of reflector gives the largest flux through all the angles shown, it necessarily follows that it should be used in preference to the other reflectors in all cases where the light is desired through these angles. It should be remembered that the uniformity of the illumination is sometimes of the greatest importance, and that in many cases it will be found that the more concentrating reflectors will give too great illumination at and near the center of the field, as compared with the illumination at the portions of the field more distant from the center.

Table II shows the easiest way to get an idea of what particular

TABLE II.

Lamp	Lumens generated per watt	Lumens effective per watt: Light ceiling Light walls 60 %	Lumens effective per watt: Light ceiling Dark walls 50 %
Mazda	8	4.8	4
Tantalum	5.5	3.3	2.75
Gem	4	2.4	2
Carbon	3.5	2.1	1.75

lamps can be expected to accomplish. After all, the first thing we want to know about a lamp of any type is how much light

it gives, and we do not primarily want to know what is its maximum or downward candle-power, nor what is its mean lower hemispherical candle-power. What we first need to know is the total flux generated and we can express this in mean spherical candle-power or in lumens, which ever we desire. In regard to the rating of lamps, Dr. Steinmetz's book[1] expresses the matter so tersely that I think it well worth quoting. He says:

> Photometrically and in illuminating engineering, only the mean spherical intensity, which represents the total flux of light, and the distribution curve, which represents the distribution of this light in space, are important. Downward and maximum candle-power obviously have no meaning regarding the light flux of the lamp, but merely represent a particular feature of the distribution curve. Hemispherical candle-power is used to some extent. It is a mixture between light flux and distribution, and as it gives no information on the total light flux nor on the actual distribution curve, and may mislead to attribute to the lamp a greater light flux than it possesses, by mistaking it for mean spherical candle-power, it has no excuse for existence and should not be used.

The table shows the number of lumens generated per watt by different types of incandescent lamp and is not difficult to remember. It is not worth while to try to remember that a 100-watt tungsten lamp generates so many lumens, or that a 40-watt tantalum lamp generates another definite number. The easiest way is to remember the number of lumens per watt produced by the type of lamp, and to obtain the actual lumens by multiplying this figure by the watts taken. Now the Mazda lamps generate about 8 lumens per watt. This figure is well worth carrying in mind. It will tell us what we can expect to accomplish with this type of lamp.

There are some types of illuminant of which photometric curves cannot be made, on account of the fact that the light is unsymmetrically distributed, such lamps for example as the Moore tube and the mercury-vapor arc. The only way the light of these lamps can be compared with incandescent lamps is by ascertaining the total flux and the number of watts required to produce it. The fact was recently brought out that the Moore tube generated 5 lumens per watt; or, in other words, that the Moore tube had an efficiency slightly lower than that of the tantalum lamp. The mercury-vapor lamp, assuming as correct

[1] Radiation, Light and Illumination, pp. 184, 185.

the mean candle-power values given in the manufacturer's bulletins, generates about 11 lumens per watt.

If we can carry the above figures for total flux per watt in mind we have something valuable in practical work. The next step is to remember about what proportion of the flux generated we may expect to have effective on the plane of illumination. The Mazda lamp is said by one manufacturing company to give about 5 lumens effective per watt with light ceilings and light walls, and 4 lumens effective per watt with light ceilings and dark walls.

Table II gives in per cent. of flux generated the proportion effective and the actual lumens effective per watt derived from these percentages. If, however, we can remember the number of lumens per watt given by the lamp and in addition these percentages, we can calculate all the rest very easily. Take for instance the metallized filament lamp with light ceilings and light walls. All we have to remember is that this lamp gives 4 lumens per watt and that the percentage effective for light ceilings and light walls is 60. These percentages are given on the assumption that the installation is correctly laid out. If incorrectly laid out, we shall not get such good results.

Last year I took up the methods of ascertaining the flux of any light source from its photometric curve, and described the methods which at that time were of principal practical value. Since then there has been progress. Again I shall describe the methods most useful in practical work. They are all of them really approximate methods, but they are, nevertheless, sufficiently accurate. One method which I described last year was the "selected angle" method which was first described by Mr. Macbeth.[1] This is one of the simplest means of obtaining mean spherical or mean hemispherical candle-power from the photometric curve. The idea is to make for each hemisphere, ten special readings of the candle-power from the curve; add them together, and divide by ten. The result is the mean upper or mean lower hemispherical candle-power, as the case may be. The vital point of the method is that you have to choose the correct ten angles. It is a very simple system but it, of course, requires remembering what the ten angles are. Where much

[1] *Illuminating Engineer*, March, 1908.

calculation of flux of a routine character is done by this method, a celluloid protractor is generally used, upon which the special angles are marked off. Mr. Macbeth, however, has gone further than this and has published special photometric paper, on which at the proper angles, dotted lines are drawn. With this paper, after the curve has been plotted, all you have to do is to read off the candle-power at the special angles, add up the values and divide by ten.

Mr. Wohlauer, the inventor of "fluxolite" paper has shown[1] that the flux through any zone of the sphere is directly proportional to the distance from the vertical to the point on the photometric curve at the middle of the zone, and the idea of his "fluxolite" paper consists in superimposing certain lines on an ordinary polar diagram by means of which lines it is easy to read off these distances directly in lumens. I have a sample of this paper here and also a sample of Macbeth's paper.

One disadvantage of the "fluxolite" paper method is that it necessitates the plotting of curves on special paper, and in addition the extra lines obscure the diagram and make it hard to read. A way of getting around the difficulty is to use the ordinary polar diagram and to measure the distances proportional to flux, by means of some scale. For instance, if you are making the measurements on a number of photometric curves of which the candle-power divisions are the same, you can make a scale which will read directly in lumens.[2]

When, however, there are no appliances at hand, no celluloid scales, nor special diagrams, etc., the simplest way to ascertain the flux for any zone from a photometric curve is, in my opinion, to take a sheet of paper or a card and mark on the edge a zero point. Put this zero point on the vertical line of the diagram and mark off along the edge of the paper or card the distance from the vertical line to the point of the curve at the middle of the zone, and then measure this distance in the candle-power divisions of the polar diagram. If you multiply the result by a constant, which for 10 degree zones is 1.095[3], you have the flux in lumens.

For instance, if we take the distance from the vertical to the

[1] *Illuminating Engineer*, February, 1909.

[2] Codman and Rolph, *Illuminating Engineer*, May, 1909.

[3] Codman and Rolph, *Illuminating Engineer*, May, 1909.

point of the curve at 15 degrees, we have a measure of the flux between 10 and 20 degrees. If we want to get the total flux from zero to 20 degrees, we can do so by adding together the values for the zones, zero to 10, 10 to 20. Another way of accomplishing this last result, when we want simply the total flux and do not care for the division of it, is to take a piece of string, put the end down on the vertical, lay off the distance to the 5 degree point of the curve, place the point of the string so found on the vertical, and lay off the distance to the 15 degree point, and so on. The final length of the string will be proportional to the total flux. To ascertain the flux in lumens, measure the string in terms of candle-power and multiply by 1.095, or for rough work, add 10 per cent.

There is still another method of calculating flux, especially when it is desired to make permanent records of all zonal values. This method will be understood from Table III. In the

TABLE III.

Angle	Candle-power	Constant	Zone	Lumens
5		0.0954	0-10	
15		0.283	10-20	
25		0.463	20-30	
35		0.628	30-40	
45		0.774	40-50	
55		0.897	50-60	
65		0.992	60-70	
75		1.058	70-80	
85		1.091	80-90	

first column are the angles with the vertical. The second, headed "candle-power," is left blank, and is to be filled in with the corresponding values of the candle-power. In the fifth column are to be placed the values for the lumens corresponding to the zones indicated by the fourth column, and these values for the lumens are found by multiplying the candle-power values opposite by the constants in the third column. A supply of sheets, each with such a table, can be printed containing the angle values and the constants, and the other values can be filled in, for different light sources. If duplicate sheets are desired, blue prints can be made.

DISCUSSION.

H. E. Clifford:—I wish to add a word to the emphasis which Mr. Codman has laid on doing away with everything except the mean spherical candle-power. I was much disappointed in reading the latest book on this subject, to find that in regard to the various light sources intended for street illumination the tabulation is given in mean lower hemispherical candle-power. This is an absolutely misleading factor, as Steinmetz and Codman have both pointed out, and it seems to me that the time has arrived when mean spherical candle-power (or lumens or light flux) is the one factor which really gives us any indication whatsoever of the value of the source of light for illumination purposes.

I am interested in Codman's string method. I have used a somewhat similar method with a sliding scale, and I find that you can read off the mean spherical candle-power or flux-of-light in lumens in almost no time at all. With a celluloid sliding scale, you can find the flux in a very simple manner indeed. Those of you who have followed the methods of finding the flux of light know it started with the Rousseau diagram. Then Kennelly had the straight edge and the compass; then Macbeth's method came, and now this method of Wohlauer is the simplest.

J. S. Codman:—One thing more. When photometric tests are made, if the readings are made at the angles, 5, 15, 25, 35, etc., we can get all our flux values allowed for in the last table directly from the test values of candle-power by inserting these test values in the candle-power column opposite the proper angles and then multiplying them by our constants. In this case we do not have to draw any photometric curve, and we gain both in rapidity and accuracy. The principal use of the photometric curve is, after all, to get a picture of the light distribution, but in a good many cases this picture is not required and when such is the case we can, with the above given method, dispense with the photometric curve altogether.

A paper presented at a meeting of the New England Section of the Illuminating Engineering Society, Boston, Mass., June 13, 1910.

STREET ILLUMINATION

BY C. O. BAKER.

Ever since its introduction the arc lamp has been the standard unit for street illumination, except for parks, boulevards and thickly wooded residence districts where local conditions and a sentiment against overhead wires and fixtures demanded a small unit. In such localities the economy of oil, gas and naphtha lamps enabled these units to maintain a substantial footing. Where the units were not closely spaced or where they could be operated in series with arc lamps to fill in intervening dark spaces the use of carbon lamps increased to some extent, but outside of the New England States up to three years ago carbon lamps were regarded more in the light of a makeshift for an impecunious municipality than as a serious factor in street illumination.

The low efficiency of carbon lamps and even "Gem" lamps restricted their size, 40-watt lamps appearing to be the standard. The tungsten lamps placed on the market later were used cautiously at first to replace carbon lamps of the same horizontal candle-power measurements. Then the possibilities of tungsten lamps for street lighting became apparent and a hitherto neglected branch of engineering suggested many new adaptations of the incandescent lamp until now street lighting with this unit has become a prominent and profitable source of central station revenue. Nor is the use of tungsten lamps restricted to the smaller units: 75-watt lamps began to replace 40-watt lamps and 100-watt lamps are now in extensive use, while 250-watt lamps are replacing arc lamps hung high above the plane. Recently the writer had occasion to figure on an installation for which 500-watt lamps were specified.

The argument at first advanced in favor of tungsten lamps was that with an efficiency approximating that of the arc, small units could be used nearer the plane and closer together to give

a more uniform distribution of light without a great, if any increase in operating expenses, while the areas darkened by outages would be minimized. Now, however, the so-called "Mazda" lamp is offered as another competitor of the arc for this work.

A divided opinion exists on the subject of effective street illumination. The merchants of some of the enterprising Western towns have organized to maintain quite elaborate lighting systems. It has seemed to the writer, however, that the "Great White Way" idea, while admirable in its intent and especially happy as a source of income to the station operator and the lamp manufacturer, except as a drawing card during a county fair, or a presidential visit, has little to commend it at night from an artistic standpoint. Moreover, the unsightly appearance of the construction by daylight is far from the "City Beautiful" idea, which demands the removal of light and telephone wires and poles and limits the projection of electric signs.

Also, the writer believes that there can be no question that any intense illumination of the streets must detract from the window displays, a fact that merchants must deplore, having in mind the potential value of their show-windows for advertising purposes.

The merchants of some towns have subscribed for attractive standards placed along their principle streets with one or a number of lamps mounted in opal, ground, or prismatic glass globes. The effect of this arrangement is excellent and quite worthy of the enterprise it suggests.

The parks, boulevards and some of the more important residence streets of large cities are now being lighted by "Mazda" units in place of gas or gasoline units, the conventional lamp post fixtures having been little improved as far as efficiency is concerned. A considerable installation of these is being made along the Charles River Basin in Boston, while Central and Prospect Parks and Riverside Drive in New York are similarly lighted. To maintain a harmonious outline however, fixtures of this type cannot be of sufficient diameter to permit the introduction of a reflector large enough to be of much practical benefit.

This class of work can all be regarded as decorative lighting

somewhat outside the work of the illuminating engineer. Lamps are placed at convenient intervals without regard to foot candles at the plane. Certain difficult problems in electrical construction are worked out by the electrical engineer, but the cost is seldom computed in any terms of lumens per watt or watts per foot candle.

In regard to economical street lighting, however, the situation is different. Formerly, when the energy consumption per unit was high, little attention was paid to accessories. When it was found that by using tungsten lamps this energy consumption could be decreased 50, 60 or perhaps even 75 per cent. there appeared to be something further in this question of economical distribution of light, and accessories were designed to effect it. It would seem however, that the idea that money can be saved by the use of suitable reflectors, is not yet fully appreciated, judging by the number of old style fixtures which are still being bought and even specified by those considered competent to draw up otherwise carefully worked out specifications.

When incandescent street lighting fixtures are considered many no doubt have in mind the old type standard fixture with a 14 in. hood and convex deflector, which serves as little else than a housing for the socket and a protection to the lamp against falling sleet and snow. Though some may realize this, they may not have figured out the exact economy of some of the later types of street fixtures; for example, fluted reflectors of porcelain enameled steel supported by protecting hoods of galvanized iron with high tension mica insulators, etc., which cost, say 50 per cent. more than the kind formerly used. In order to place matters on a comparative basis, the following figures are given.

Let us consider the 40-c-p. (50-watt) Mazda lamp, for example, as this is used more generally under the old style 14 in. convex deflector. This arrangement is designated Unit *C* in contradistinction to the 18 in. flat-fluted reflector of modern type, designated as Unit *W*.

Fig. 1 shows the position of the lamp under deflector *C*. It will be noted that no light radiating from the center of the bare

lamp is intercepted by this deflector below an angle of 135 degrees. The total flux density of a 50-watt series Mazda lamp is 395 lumens. Within a zone above 135 degrees are 24 lumens, just 6 per cent. of the total lumens available for diversion to a useful direction by reflector *C*.

If the 18 in. flat-fluted reflector *W* were placed on a level with the bead on the socket skirt (the most practical position). light radiating from the center of the lamp would be intercepted at 110 degrees. Within a zone above 110 degrees are 87 lumens or 22 per cent. of the total flux available for purposes of reflection. Hence Unit *W* intercepts 3 2/3 times as much

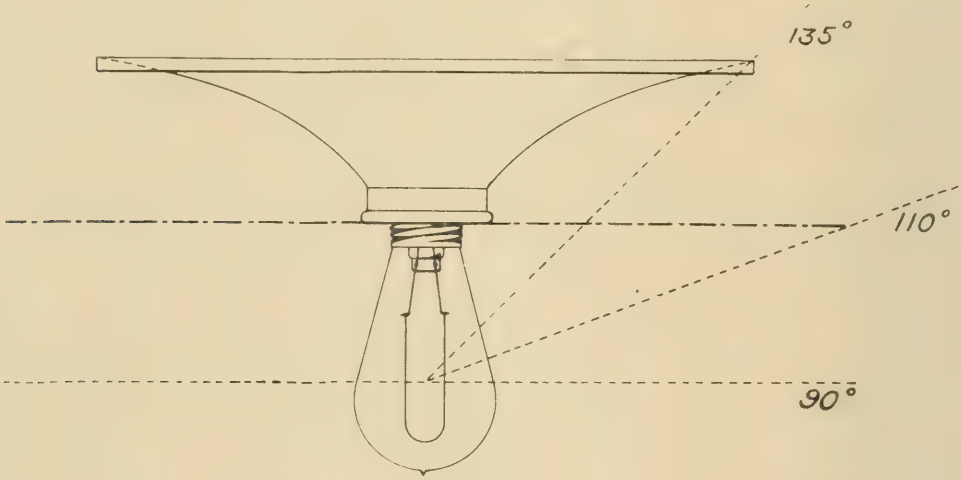


Fig. 1.

light as Unit *C* and by being flat diverts the light outwards and downwards below the horizontal, where it can all be used for street illumination.

It has been the practice to hang the older type fixtures (Unit *C*) 14 to 16 feet above the street level, at which height the light radiating above 80 degrees towards the street would meet the plane, if at all, too far away (at 80 degrees 14 ft. high = 79½ ft. distance; 16 ft. high = 91½ ft. distance) to give any appreciable intensity in foot candles at the plane. Hence for our purposes we need consider only the flux density within a zone below 80 degrees.

Fig. 2 shows the distribution (curve *L*) around a bare 50-watt Mazda lamp, (curve *C*) Unit *C*, and (curve *W*) around Unit *W*. The total zonular flux below 80 degress in a bare 50-

watt Mazda lamp is 176 lumens, that of Unit *C* 192 lumens and Unit W 236 lumens. Then, as reflector *C* increases the zonular flux 16 lumens or 9 per cent. and reflector *W* increases it 60 lumens or 34 per cent. Unit *W* increases the useful light of the bare lamp 25 per cent. more than Unit *C*. A practical application of these data may be of interest.

Let us assume that a station with a thousand 40-c-p. (100-watt) Gem lamps in circuit under *C* reflectors replaces these

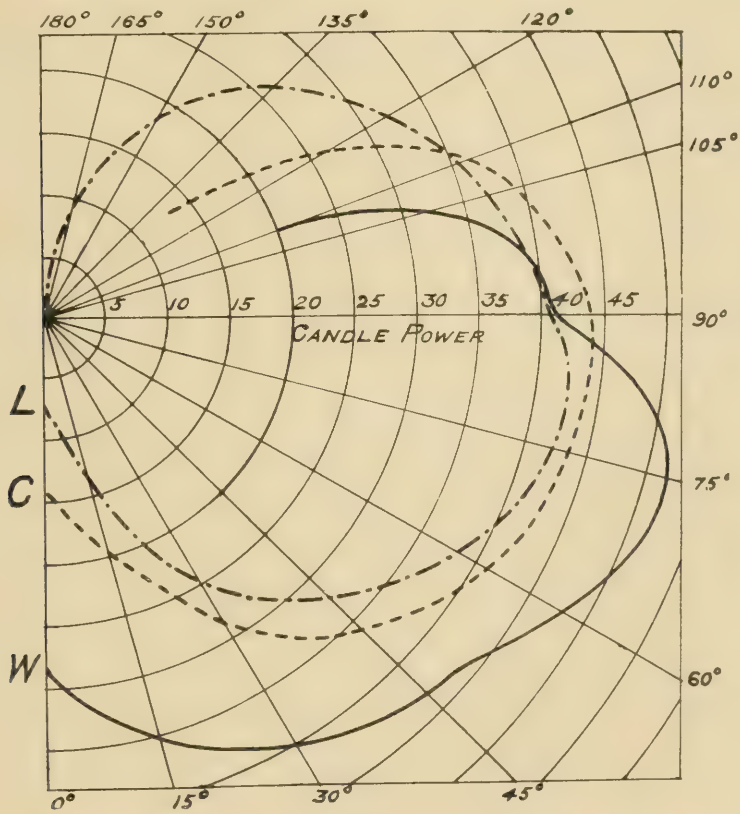


Fig. 2.

with 40-c-p. (50-watt) Mazda lamps. On a 2,000 hour schedule with a current cost of ½ cent per kw., an annual saving of $500.00 is effected in the cost of energy alone, with a surplus output of 100,000 kw. from the same generating apparatus which can be devoted to some other source of revenue. This sounds like twentieth century progress, but there is more in sight. When the station operator contracted for 40-c-p. lamps under reflector *C*, he was giving his customer a unit with approximately 37 M. Z. C. within 80 degrees. Presumably, this

was satisfactory. Now, if by using reflector *W* he increases this M. Z. C. 25 per cent. over that with Unit *C*, he will be giving an unnecessarily good measure. Consequently, he may replace Unit *C* with the reflector *W* over a 32-c-p. (40-watt) Mazda lamp giving approximately the illumination he contracted for and effecting a further saving of $100.00 per year. Perhaps an operator with a new equipment of reflectors *C* will not see where he can profitably scrap this and buy a new outfit, but an operator with a new equipment of reflectors *C* will not see $100.00 a year capitalized at 6 per cent. would mean an investment of $1,667.00, which a new station can add to its previous appropriation for reflector *C* (which it may have considered buying) with a certainty of a net earning of 6 per cent. and the added satisfaction of having the latest equipment.

In the course of the writers regular duties he is frequently asked why the Maza lamp is to be preferred to the arc lamp for street lighting, and he endeavors to answer it by regarding the intrinsic brilliancy of the unit to the exclusion of its nature, since we are dealing primarily with effects. The prime requisite of illumination for any purpose is uniformity, and in street lighting this illumination need not be intense if we can eliminate contrasting zones of brightness and comparative darkness. Mazda lamps of a candle-power equal to that of arc lamps would be as objectionable as the latter for general purposes. The special purpose of the Mazda lamp is to afford a high efficiency low candle-power unit which by frequent spacing near the plane will give a greater uniformity in illumination than it is possible with larger units placed higher and at greater intervals.

Furthermore, it is necessary to place light sources of high intensity above the line of vision to avoid a dazzling fatiguing effect on the eye. Smaller units can be placed sixteen feet above the street level to clear high loads and overhanging foliage, or as low as twelve feet in strictly residential districts.

As a comparison of the lighting values of the two units a table of measurements, given by Mr. Walter Allen in his paper read before the New York section last year, can be used to advantage.

Direct-current, 6.6 ampere enclosed arc lamps were spaced

400 ft. apart, 21 ft. above the street level. Measurements were taken over a distance 200 feet each side of the lamps, about 14 ft. out from the lamp line. These gave a maximum of 0.185, a minimum of 0.003, and an average of 0.0475 foot candles. If three 100-watt Mazda lamps under reflectors *W* were placed 150 ft. apart and 12 ft. high, they would cover about the same distance. A table of measurements under these conditions gives a maximum of 0.205, a minimum of 0.006, and an average of 0.063 foot-candles, all higher, it will be noted, than the measurements from the arc, with less variation from the mean.

The writer is frequently asked for a standard of intensity for street illumination. One authority has said that for residence streets, illumination should be kept above 0.004 foot-candles. This is probably about right, although I am sure many of those present live in suburbs around Boston which are considered sufficiently well lighted, but where 75-watt lamps are placed on each alternate service pole about 220 ft. apart, when of course, no such illumination as 0.004 foot candles is anticipated.

In Mr. Allen's paper, however, he characterizes an installation where 40-c-p. tungsten lamps are hung 16 ft. high on trolley poles 100 ft. apart, as being far more pleasing and effective than that with the arc lamps spaced as already stated.

In conclusion, it may be said that for street lighting purposes fixtures are required with effective reflectors, preferably flat-fluted for a wide and even distribution, porcelain enameled for permanence of the reflecting surface, neither more nor less than 18 in. in diameter for units up to 100-watts, so as to offer a minimum of surface to wind stress, and protected against the lodgment of snow and sleet by a hood with a smooth rounded surface, rigidly secured to a bracket, with a high tension insulating joint, preferably mica for the sake of appearance, and not extending out beyond four feet from the curb. The sheet metal parts should be heavily galvanized before painting and where the fixtures are to be used in exposed locations along the coast, the brackets and cast metal parts may also be galvanized. The galvanizing of the steel hoods is sufficient to insure their permanence and the expense of copper hoods is quite unnecessary if the galvanizing of the steel is well done after the metal is formed.

DISCUSSION.

Mr. Foster:—In surburban lighting the greater part of the light is within 25 ft. of the source, while further off it is dark. An example of this may be found here in Boston, I would like to ask if the author can suggest any way to overcome that very obvious weakness. So far as I can see where the light is up as high as mentioned, the people on the street get very little light except for a few feet.

Mr. C. O. Baker:—I have had that in mind. Bulletin 7A just issued by the engineering department of the National Electric Lamp Association discusses this point. Referring to Fig. 3, the full line represents the curve of the arc. The

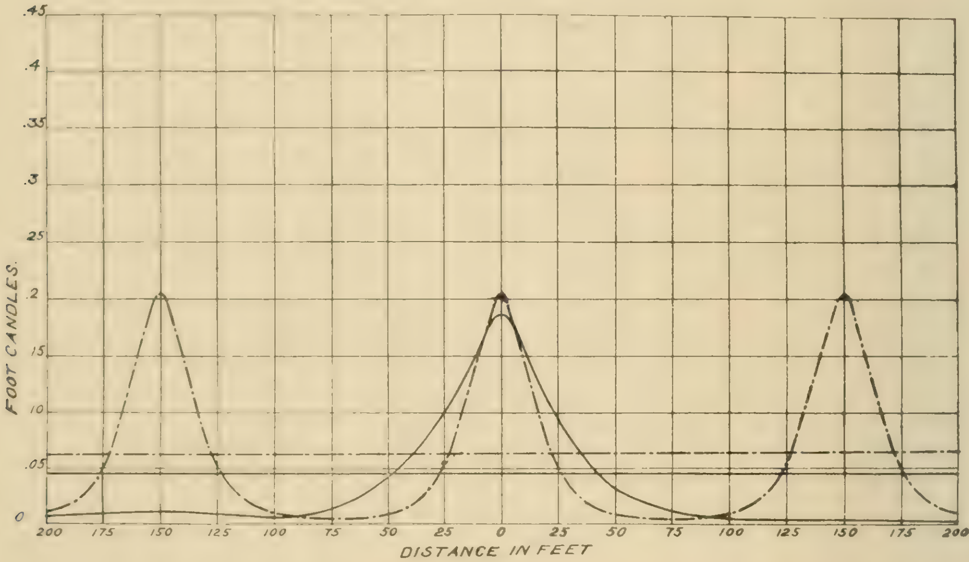


Fig. 3.

measurements given in Mr. Allen's paper were with 6.6 ampere d. c. enclosed arcs spaced 400 ft. apart, the measurements being taken over a distance of 200 ft. each way. These measurements gave a maximum of 0.185, a minimum of 0.003 and an average of 0.0475 foot candles. Now if three 100-watt Mazda lamps were equally spaced over the same distance, a table of measurements under these conditions gives a maximum of 0.205, a minimum of 0.006, and an average of 0.066 foot candles. With 3/5 of the same energy consumption divided between the three 100-watt lamps, we have a greater maximum, a greater minimum, and a greater average than with the arc.

Mr. Smith:—What is considered the proper light for street illumination in foot candles?

Mr. C. O. Baker:—One authority gives it as not less than 0.004 foot candles. Mr. Allen states in his paper that a certain installation with 40-c-p. tungsten lamps placed 100 ft. apart and 16 ft. high gave a minimum of 0.007 foot candles (which he considered far more satisfactory illumination than with the arcs) and gave an average of 0.013 foot candles.

Mr. Smith:—Then in all parts of the street on which the Mazda lamps were installed as represented in Fig. 3, there would be what is conceded to be good illumination?

Mr. C. O. Baker:—Yes, there would be a minimum of 0.006 foot candles. If 0.004 is considered a sufficient minimum, there would still be a surplus —0.004 as against 0.006 foot candles.

Mr. R. C. Ware:—In the maximum for the arc given in Fig. 3 is not the decimal point misplaced? What was the height?

Mr. C. O. Baker:—Twenty-one feet.

Mr. R. C. Ware:—Was that in the middle of the street or in the line of the lamp?

Mr. C. O. Baker:—About 14 ft. outside of the line of the lamp. In his paper Mr. Allen gives as a maximum 0.177 for series enclosed-arc lamps, an average of 0.036, a minimum of 0.003, and an average variation from mean per cent. of 106.9, while with the tungsten series mentioned the average variation from mean per cent. was 33,—much more uniform.

Mr. R. C. Ware:—At what distance from the lamp is the maximum obtained?

Mr. C. O. Baker:—The maximum was directly opposite the lamp and the minimum was 200 ft. away from the centre With measurements made in a line with the lamp, Bulletin 7A, already referred to gives the maximum at about 0.23, which is very close to that of 0.185 given in Fig. 3. The bulletin shows that at 50 ft. away these were 0.10, and at about 35 ft. away, 0.15 foot candles, in this case, 550-watt d. c. multiple enclosed-arc lamps being used.

Mr. Smith:—Will some one explain the international candle-power which is being standardized?

Mr. J. S. Codman:—It is the same unit used in France and

Great Britain, as I understand it, our unit being different. We have changed our unit to agree with the English and French units.

Mr. R. C. Ware:—The hefner, the German standard, has always been 0.9 of the English standard and the French has been the same as the English. The American standard was allowed to run up a little, so that the hefner was only 0.88 of the American electric candle. The American gas candle remained practically the same as the English. The international standard eleminates the American and adopts the English or French, which is 0.9 of a hefner. In other words France, England and the United States agreed to make their standard the same, the United States modifying its unit to agree with the French and English. The German unit is still the hefner.

Mr. C. O. Baker:—With reference to street lighting by small units and by large units, there are some points which do not appear upon the surface. In a surburban district where arcs are used, these are necessarily spaced far apart. There is consequently a light source of high intensity almost constantly in the field of vision until one has approached to within 50 or 60 ft. of the lamp. The high intrinsic brilliancy produces a distinctly unpleasant sensation on the eye, and stops down the pupil, so that the apparent illumination produced, so long as the lamp is in the field of vision, is seemingly much less than is actually the case.

On the other hand, where larger units are close together and high in the air, resulting in a higher average illumination throughout, the stopping down of the pupil is less in proportion to the illumination produced, and has, therefore, less apparent effect in decreasing the usefulness of the illumination resulting. In the case of the small unit lighting by tungsten lamps, which gives the high average mentioned by Mr. Baker, there is a series of high peaks and low minimum points in close succession. Furthermore, the lights are hung low and are practically always in the field of vision. The result is that in traversing a street lighted in this manner, the eye experiences a series of more or less violent shocks, owing to the rapid transition from low to

high illumination values and vice versa, and is unable to accommodate itself to the constantly changing conditions.

There is further the disadvantage that the constant glare of the filament in the eye stops down the pupil so that there is practically no apparent illumination at the low points and the advantage of the high average is largely lost. While the objection is not of such great moment where the intrinsic brilliancy of the light source is comparatively low, it seems to me that in all cases of small unit street lighting, and especially where bare metallic filament lamps are used, the solution is in the use of some kind of a reflector which will protect the eye.

A prismatic reflector now on the market gives a satisfactory vertical and horizontal distribution, which covers the point fairly well. There is, however, another and perhaps more satisfactory way which might be worked out. Many of you have probably noticed the very pleasant effect produced when driving along a heavily wooded street where the lamps are hidden from the eye by the leaves, and yet not so completely shadowed as to keep the light away from the road. It is not often you will find that.

The effect would be the same as that produced by having a reflector with an opaque bowl perhaps 18 in. in diameter, so that the light above 10 degrees below the horizontal is reflected back at 10 degrees and yet all the direct light below 10 degrees goes out, the bowl being sufficiently shallow to allow this. If such a reflector were worked out, the result would be good.

Mr. C. O. Baker:—Some two years and a half ago I attained that result for a railway by making parabolic reflectors and extending the skirt down to the lowest level of the filament. It had decidedly the effect mentioned and worked very nicely. The company wanted to light their train sheds and platforms and at the same time shield the light from the eyes of the trainmen so that the lights would not be confused with the signals.

Mr. R. C. Ware:—Of course the chief objection to that is that it does limit the distance from lamp to lamp. They must be spaced near enough to allow the highest beams to cross, because the vertical illumination is needed as much as, if not more than, the horizontal.

Mr. Smith:—With regard to arc lamps, in the data given, the arc lamp was not in any way equipped with a reflector. It was really a hood. Would it not be possible to equip the present arc lamp or the later arc lamps with a reflector whereby their efficiency for street lighting could be greatly increased?

Mr. C. O. Baker:—The reason all arc lamps have not been equipped with reflectors is that with the later types of arc lamps the claim is made that the distribution of light is very much below the horizontal and as they must be hung high in order to be out of the line of vision, it really is not essential to have a reflector. I notice that the magnetite arcs around Boston are all equipped with reflectors as large as it is proper to make them, on account of the severe windage. Twenty-four inches is almost too large to withstand a wind stress. I believe one company uses a reflector 20 in. or 22 in. It may have the effect of being simply a hood, but I think it has considerable reflecting value.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. V. OCTOBER, 1910. NO. 7

MINUTES OF COUNCIL MEETING.

OCTOBER 13, 1910.

A meeting of the Council was held on October 13, 1910, there, being present President Hyde and Messrs. Israel, Lansingh, Morris, McAllister and Millar.

There was presented to the Council a report of the Lecture Committee which has charge of arrangements for the lecture course to be held under the joint auspices of the Illuminating Engineering Society and the Johns Hopkins University. This report was accepted and approved.

The Executive Committee which transacted business of immediate importance during the summer reported on its July and August meetings. The most important items of the report were the election of 250 applicants at the July meeting and 212 applicants at the August meeting; the approval of vouchers for payment of bills aggregating $540.02 covering expenditures which bore the approval of the Finance Committee; the resignation of Mr. George A. Wardlaw, as Chairman of the Committee on Editing and Publication, and the appointment of Dr. A. S. McAllister as his successor.

The Finance Committee, Mr. L. B. Marks, Chairman, arranged a report which included the approval of payment of vouchers aggregating $2,508.10.

The Finance Committee submitted a recommendation that all expenses of the 1910 Convention save entertainment expenses only be paid out of the Society's funds.

The report of the Finance Committee was accepted and approved by the council.

The General Convention Committee, through its Chairman, Mr. V. R. Lansingh, submitted a report on plans for the Balti-

more Convention which showed preparations to be progressing satisfactorily.

The General Secretary's statement of the financial status of the Society as of October 1st, 1910, was as follows:—

Aggregate receipts	$10,006.11
Aggregate disbursements	5,175.33
Bank balance	4,830.78
Accounts payable	2,276.49
Accounts receivable	1,869.21

The status of membership was also reported upon as follows:

Members at beginning of year	1,038
Elected subsequent to Jan. 1st	504
Dropped for non-payment of dues	5
Resignations accepted	62
Membership October 1st	1,475
Applications to be passed upon	59

The final report of Mr. J. Robert Crouse, Chairman of the New Membership Committee was presented. This showed that 500 applications for membership in the Society have been received as a result of the activities of the Committee. (About thirty additional applications have been received since the date of this report.) The Council received the report with approval and discharged the Committee with a vote of thanks for the very praiseworthy conduct of the campaign and for the gratifying results obtained.

SECTION MEETINGS.

NEW YORK SECTION

A meeting of the New York Section was held on October 13, at which time three papers were presented on the general subject of street lighting, as follows. "An Unrecognized Aspect of Street Illumination" by Mr. Preston S. Millar; "A Scientifically Designed Street Lighting Unit" by Mr. Herbert S. Whiting; "A recent Street Lighting Installation in the National Capitol" by Mr. Albert Jackson Marshall. Demonstrations were made in connection with the first two papers while lantern slides were used with the last named. Mr. Millar's paper appears in this issue.

The secretary announced that at the November meeting a general

review will be given of the papers presented at the Convention. At the November meeting there will be a paper by Prof. E. L. Nichols on "The Early History of Photometric Standards" and two papers by Mr. Bassett Jones, Jr., entitled "A Study of Reflecting and Diffusing Media" and "The Lighting of the Allegheny Soldiers' Home in Pittsburg."

Mr. W. H. Gardiner, Jr., was elected manager to succeed Mr. S. G. Rhodes, who had resigned.

CHICAGO SECTION.

A meeting of the Chicago Section was held on Thursday, October 13th, in the Chicago room at the Great Northern Hotel. A paper was read by Mr. Jos. Newman, Jr., on the subject "Good Lighting from a Factory Viewpoint." The discussion was led by Mr. C. W. Price, Mr. W. E. Walter, Mr. Frost, Mr. Hunt and Mr. Morgan.

Mr. F. H. Barnhard was elected secretary of the Section for the coming year and it was agreed that his duties will begin with the arrangements for the November meeting.

PHILADELPHIA SECTION.

At a meeting of the Philadelphia Section held on October 21st a paper was presented by Mr. F. H. Gilpin entitled "Effect of the Variation of the Incident Angle on the Coefficient of Diffused Reflection."

BALTIMORE CONVENTION.

The Fourth Annual Convention of the Society was held at Johns Hopkins University, Baltimore, Md., on Monday and Tuesday, October 24th and 25th. The registered attendance reached the unexpected total of 244.

The opening exercises were held at 10.00 A. M. on Monday when the address of welcome to the city was delivered by Hon. J. Barry Mahool, Mayor of Baltimore, and Dr. Ira Remsen, President of Johns Hopkins welcomed the Society to the University. President Edward P. Hyde then delivered his presidential address having for its title "The Goal of Illuminating Engineering." The address appears in this issue.

The Committee on Nomenclature and Standards, of which Dr. Alexander C. Humphreys was chairman, submitted as its report the report of the Sub-committee on Photometric Units of which Dr. Clayton H. Sharp was chairman. Action on this report, containing certain recommendations concerning photometric quantities and symbols, was deferred for one year so as to enable international agreement to be reached before making a final selection of symbols, etc. The Committee on Division of Membership, of which Mr. E. L. Elliot was chairman, submitted a report recommending a division of membership when the full membership shall so decide and in a manner to be determined by the membership. This report was accepted and the committee was discharged.

On Monday afternoon the following papers were presented: "Central Station Illuminating Engineering Department Work and Methods Applied by the Denver Gas and Electric Company," by C. F. Oehlmann; "The Effect of Light on the Movement of Lower Organisms," by Prof. Samuel O. Mast; "Illuminating Engineering Sheets for the Calculation and Recording of Data," by J. S. Codman; and "Some Neglected Considerations Pertaining to Street Illumination," by Preston S. Millar.

On Monday evening Mr. V. R. Lansingh delivered a popular lecture on "Illuminating Engineering" intended particularly for the benefit of the people of Baltimore.

At the morning session on Tuesday the following papers were presented:

"Relations Between Pressure and Light Output with Various Gas Lamps and Burners," by Norman Macbeth; "Some Spectral Luminosity Curves Obtained by Flicker and Equality of Brightness Photometers," by Dr. Herbert E. Ives; "The Temperature Rise Due to the Energy Radiated in the Lower Hemisphere from Different Light Sources," by J. G. Felton and E. J. Brady; and "Report of Progress on Flame Standards," by E. B. Rosa and E. C. Crittenden.

The final session of the convention was held on Tuesday afternoon when the following papers were presented:

"The Value of Illuminating Engineering to the Commercial Man," by W. J. Serrill; "Practical Value of Illuminating Engineering to the Central Station," by J. F. Gilchrist; and "The Value of Illuminating Engineering to the Manufacturer," by V. R. Lansingh.

Among the entertainment features were an automobile ride for the ladies through the suburbs of Baltimore on Monday afternoon, a reception to the members of the Society and their guests at the Hotel Belvedere on Monday evening, a trolley trip and luncheon for the ladies at the Baltimore County Club on Tuesday morning and afternoon and a banquet at the Hotel Belvedere on Tuesday evening. At the banquet, Gen. George H. Harries acted as toastmaster. Toasts were responded to as follows:

"Baltimore's Hospitality," by Mayor Mahool; "The Importance of University Training to an Engineer," by Dr. Remsen; "The Function of the Illuminating Engineering Society," by Dr. Hyde and "Illumination on Current Topics," by Ex-mayor Ferdinand C. Latrobe.

JOHNS HOPKINS UNIVERSITY COURSE IN ILLUMINATING ENGINEERING.

On Tuesday afternoon were held the opening exercises connected with a lecture and laboratory course in illuminating engineering offered by the Johns Hopkins University in cooperation with the Illuminating Engineering Society. The opening addresses were made by President Remsen of the University and President Hyde of the Society. Short addresses were then delivered by the following representatives of various societies. Mr. H. A. Wagner for the president of the Association of Edison Illuminating Companies; Mr. W. W. Freeman as president of the National Electric Light Association; Mr. W. C. Morris for the president of the American Gas Insitute; Dr. J. B. Whitehead for the president of the American Institute of Electrical Engineers; Dr. Samuel Theobald as president of the American Opthalmological Society; Dr. Wendell Reben as president of the American Academy of Oto-Laryngology and Opthalmology, and Mr. J. R. Sloan as president of the Association of Railway Electrical Engineers.

The course of lectures owes its origin to the following considerations:

The Illuminating Engineering Society recognizing the fact that there is an increasing demand for trained illuminating engineers and that the facilities available for the specialized instruction required were inadequate, determined, through an act of the Council of the Society, to encourage the establishment of a course of lectures on the subject of illuminating engineering. It was recognized that the course should have three objects: (1) to indicate the proper co-ordination of those arts and sciences which constitute illuminating engineering; (2) to furnish a condensed outline of study suitable for elaboration into an undergraduate course for introduction into the curricula of undergraduate technical schools; and (3) to give practicing engineers an opportunity to obtain a conception of the science of illuminating engineering as a whole.

Inasmuch as such a course could most appropriately be given at a University where graduate instruction is emphasized, and

as the Johns Hopkins University regularly offered courses by non-resident lecturers as part of its system of instruction and was preparing to extend its graduate work into applied science and engineering, an arrangement was effected by which the lectures are given at this University under the joint auspices ot the University and the Illuminating Engineering Society.

The subjects and scope of lectures were proposed by the Society and approved by the University. The lecturers were invited by the University upon the advice of the Society.

The program of lectures together with the list of lecturers is given below.

The University provided facilities for demonstrations at lectures and had installed a working exhibit of apparatus for experimental work in light, illumination, and illuminating engineering. This apparatus was placed at the disposal of those who attended, and an opportunity was afforded to undertake laboratory work during the term of the lecture course under the supervision of trained experts of the University and of the Society. The complete course of thirty-six lectures is being given between the dates October 26 and November 8, 1910, inclusive.

LECTURES AND LECTURERS ON ILLUMINATING ENGINEERING.

I. "The Physical Basis of the Production of Light." Three lectures. Joseph S. Ames, Ph. D., Professor of Physics, The Johns Hopkins University.

II. "The Physical Characteristics of Luminous Sources." Two lectures. Edward P. Hyde, Ph. D., President, Illuminating Engineering Society; Director of Physical Laboratory, National Electric Lamp Association.

III. "The Chemistry of Luminous Sources." One lecture. Willis R. Whitney, Ph. D., Director of Research Laboratory, General Electric Co.; Past President, American Chemical Society.

IV. "Electric Illuminants." Two lectures. Charles P. Steinmetz, Ph. D., Past President, American Institute of Electrical Engineers; Professor of Electrical Engineering, Union University.

V. "Gas and Oil Illuminants." Two lectures. (1) M. C.

Whitaker, B. S., M. S., Professor of Industrial Chemistry, Columbia University. (2) Alexander C. Humphreys, M. E., Hon. Sc. D., President Stevens Institute of Technology; Past President, American Gas Institute.

VI. "The Generation and Distribution of Electricity with Special Reference to Lighting." Two lectures. John B. Whitehead, Ph. D., Professor of Applied Electricity, The Johns Hopkins University.

VII. "The Manufacture and Distribution of Gas with Special Reference to Lighting." Two lectures (1) Mr. E. G. Cowdery, Vice-President, Peoples Gas Light and Coke Company, Chicago, Ill. (2) Mr. Walter R. Addicks, Vice-President of Consolidated Gas Co., New York.

VIII. "Photometric Units and Standards." One lecture. Edward B. Rosa, Ph. D., Physicist, National Bureau of Standards.

IX. "The Measurement of Light." Two lectures. Clayton H. Sharp, Ph. D., Test Officer, Electrical Testing Laboratory, New York City; Past-President, Illuminating Engineering Society.

X. "The Architectural Aspects of Illuminating Engineering." Two lectures. Walter Cook, A. M., Vice-President, American Institute of architects; Past President, Society of Beaux Arts Architects.

XI. "The Decorative Aspects of Illuminating Engineering." One lecture. Mr. Louis Tiffany, President of the Tiffany Studios, New York.

XII. "The Physiological Aspects of Illluminating Engineering." Two lectures. P. W. Cobb, B. S., M. D., Physiologist, Physical Laboratory of the National Electric Lamp Association.

XIII. "The Psychological Aspects of Illuminating Engineering." One lecture. Robert M. Yerkes, Ph. D., Assistant Professor of Psychology, Harvard University.

XIV. "The Principles and Design of Interior Illumination." Six lectures. (1) L. B. Marks, B. S., M. M. E., Consulting Engineer, New York City; Past-President, Illuminating Engineering Society. (2) Mr. Norman Macbeth, Illuminating Engineer, The Welsbach Co. (3) W. E. Barrows, Jr., Assistant

Professor, Electrical Engineering, Armour Institute of Technology, Chicago, Ill.

XV. "The Principles and Design of Exterior Illumination." Three lectures. (1) Louis Bell, Ph. D., Consulting Engineer, Boston, Mass.; Past-President, Illuminating Engineering Society. (2) E. N. Wrightington, A. B., Boston Consolidated Gas Co.

XVI. "Shades, Reflectors and Diffusing Media." One lecture. Van Rensselaer Lansingh, B. S., General Manager, Holophane Co.

XVII. "Lighting Fixtures." One lecture. Mr. Edward F. Caldwell, Senior Member of Firm and Designer, Edward F. Caldwell & Co., New York.

XVIII. "The Commercial Aspects of Electric Lighting." One lecture. John W. Lieb, Jr., M. E., Third Vice-President, New York Edison Co.; Past-President, American Institute of Electrical Engineers.

XIX. "The Commercial Aspects of Gas Lighting." One lecture. Walton Clark, M. E., President of the Franklin Institute, Philadelphia; Third Vice-President, United Gas Improvement Co., Philadelphia.

The laboratory demonstrations given in connection with the lectures are under the direction of:

Charles O. Bond, Manager of Photometric Laboratory, United Gas Improvement Co., Philadelphia; Herbert E. Ives, Ph. D., Physicist, Physical Laboratory, National Electric Lamp Association; Preston S. Millar, Electrical Testing Laboratories, New York; General Secretary, Illuminating Engineering Society.

On the opening day the registration for the lectures so far exceeded the expectations of those in charge of the arrangement that a limit had to be placed upon the applications accepted Accommodations had been provided for 230 while the number of applications reached about 250.

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THE GOAL OF ILLUMINATING ENGINEERING.[1]

BY E. P. HYDE.

The inception and development of the science and art of illuminating engineering constitute an epoch in the progress of civilization. In the beginning God said "let there be light" and there was light, and for many centuries the sun by day, and the moon and stars by night were unchallenged luminaries of the earth, save for the occasional torch whose flickering rays illumined the parchment of some zealous scribe or lighted the pathway of a belated wanderer. To us of the present day who spend a fourth of our wakeful moments after the sun is down it is scarcely credible that humanity ever could have been contented without that wealth of artificial light that transforms our night into day and rescues for us many of our happiest moments after the day's work is over. And yet when we recall that a century ago gas-lighting was in its infancy, that a half-century ago the incandescent lamp was not yet invented, we realize that the dark ages are but just past, and that a new era is dawning.

It would be interesting to trace the gradual development of artificial illumination from the dawn of civilization down to the present time, but the unprecedented progress of the last few decades together with the birth and development of the new engineering science and art which seeks to know and to apply the correlated facts of natural and artificial illumination, distorts our perspective, and impels us to inquire with diligence into the *raison d'être* of illuminating engineering, and to seek to discern on the hazy horizon of the future the goal of its progress. We have but so recently embarked on our voyage and have until now been so concerned with the shallows and eddies of inland waters that there has scarcely yet been opportunity to take our bearings, to swing around the nose of our vessel toward the distant shore across the mighty intervening deep of prolonged experience, and to begin a premature vigil for a first glimpse of land. But today, on the eve of the lecture course which should establish be-

[1] Presidential Address before the Fourth Annual Convention of the Illuminating Engineering Society, Baltimore, October 24, 1910.

yond dispute our *raison d'être,* we can feel assured that we have cleared the light-vessel, have passed over the bar, and are now ready to steer by the compass to our distant haven.

Illuminating engineering is both a science and an art. Its principles rest on the correlation, after a new scheme, of the scattered phenomena of the ancient sciences of physics, physiology and psychology, and the dictates of the ancient art of architecture. Its accomplishments depend on the application of its principles to the solution of practical problems of lighting. Illuminating engineering is *slightly* complex; it touches the purely commercial on the one hand, and aspires to the highest summits of aestheticism on the other; it invokes the resources of physics and chemistry, and it depends fundamentally on the physiology and psychology of seeing. Its very complexity is sufficient explanation if its slow inception. The phenomena and laws of the sciences of physics, physiology and psychology are well established; the dicta of the art of architecture are well formulated; the correlation of those laws and dicta as a basis of practical application to lighting is a distinct achievement of the new art and science from which this Society has taken its name.

Illuminating engineering is both a science and an art. Science, according to Ruskin, is "the knowledge of things, whether Ideal or Substantial," and art is the "modification of Substantial things by our Substantial power." Science is knowledge, coordinated, classified, systematized. "The object of science is knowledge; the objects of art are works. In art truth is the means to an end; in science it is only the end." The science of illuminating engineering is the correlated knowledge of the varied phenomena of illumination; the art of illuminating engineering is the application of this classified knowledge to the design of lighting installations. The goal of illuminating engineering is therefore, the attainment to the ideal application of perfect knowledge.

The analysis of this highly generalized statement of the goal of illuminating engineering leads us first to the fundamental fact that knowledge must precede application. The future of the science, and the achievement of the art depend on the establishment of sound basic principles, and it is of paramount importance that we give our careful attention to the development of the

principles of the science, lest its vitality should be sapped by injudicious application of unwarranted assumptions. But although knowledge must precede application it is not to be inferred that the knowledge must be complete before application is attempted. Science and art go hand-in-hand. The failures in application suggest the deficiencies in the knowledge, and stimulate further inquiry. The successes in practice corroborate the theory and indicate the direction for further investigation. The knowledge and its application proceed together towards the goal of its progress.

We are tempted to-day to point out some of the convergent paths along which the correlated sciences and their companion arts are steadily advancing toward the goal of illuminating engineering. The basic element of illuminating engineering is *light,* and the normal physical prerequisite of the sensation of light is the material source, which radiates energy through the luminiferous ether to the sensitive receiving elements in the retinas of our eyes. The human retina is most perfectly adapted to the light of the sun, which will unquestionably continue without competition as the natural illuminant of exposed places in the daytime, and will remain as the standard of *quality* with which we will compare the nocturnal substitutes of human invention. The art of illuminating engineering has, indeed, grown out of the efforts of the race to imitate daylight in the use of artificial light sources, but whatever may have been its origin, its sway logically extends over the domain of daylight as well as of night-light illumination.

Though we can foresee no marked improvement nor hope for any change in our God-given daylight source, the opportunities for improvement in artificial illuminants, notwithstanding the marvelous developments of the last few decades, are well recognized, provided our standard of perfection does not move silently onward before us. Judged according to our present conception of ideality the ideal artificial illuminant, apart from any consideration of its form or magnitude, its polar diagram or its intrinsic brilliancy, or any of its numerous attributes except the quality of the light and the efficiency of its production, would transform all the energy supplied to it into luminous radiation of sunlight color. The very recital of exceptions indicates the

limitations in our conception of ideality, and yet the realization of the two conditions which have been imposed is still far from attainment.

If all the energy supplied to a lamp were transformed into radiation, and all the energy radiated were confined within very narrow limits of wave-length in the yellow-green region of the spectrum it would be possible, according to the best data available, to produce a luminous flux of about 800 lumens for every watt supplied. But this monochromatic light would be unnatural, and the appearance of natural objects illuminated by it would be uncanny. If, however, the second condition were modified so that all the energy was radiated, not within the narrow wave-length limits of a single color, but throughout the visible spectrum, the distribution of energy in the various colors corresponding to that of average daylight, the resultant light would match daylight in quality, and would correspond to an output of about three hundred lumens per watt, which is five or six times that of the most efficient artificial source of the present day. Such an efficiency is impossible in the pure temperature radiation of a black body, and is scarcely to be sought in the pure temperature radiation of any solid however selective its radiation may be, for no substance is known which indicates even the possibility of such extreme selectivity. If an output of several hundred lumens per watt is ever to be attained it should be sought in the radiation of so-called luminescence, as exemplified in the flame light of the various luminous and other arcs. A characteristic of such luminescent radiation is a discontinuous spectrum, and even though the desired efficiency might be obtained, it is improbable that the bright line spectrum would consist of so many lines and of such relative intensities that the integral quality would be that of sunlight and that the color of natural objects would be true.

But let us assume that it is possible through the developments of physical science to produce a light source of the quality of daylight and with the highest possible efficiency consistent with this quality. Let us ignore the other qualifications which we excepted in our premises. With all these exceptions, is our most efficient, white-light source perfect? It is very questionable that such is the case. Life upon this earth, as we know it, is depend-

ent on the warming influence of the solar radiation much of which is without the limits of the visible spectrum, and yet one of the conditions of our ideal source precludes any radiation except in the visible spectrum. Many destructive and constructive organic chemical processes are attributed to the ultra-violet radiation in daylight, and yet one of the conditions of our ideal artificial source implies the exclusion of ultra-violet radiation. The demands we have made upon our ideal artificial source render it unnatural, and who knows the bane or blessing involved in those very radiations which we would studiously avoid?

We speculate much on the possibilities of luminous *efficiency,* and rightly so, but we are likely to become unbalanced by narrow speculation. We cease to appreciate the full significance of *efficiency,* which I take it, signifies in its broadest meaning, the most perfect accomplishment of some desired end by the most economical means. It is the ratio of satisfactoriness to cost, and not merely the reciprocal of cost. If the aim of a lighting design is a soft yellow tint, a green light would not be efficient, whatever its lumens per watt.

We speculate much on the possibilities of luminous efficiency, and rightly so, but we should not forget to speculate also on the possibility of the utilization of the flux which is already available. We should study the source, as a necessary element in illumination, but the emphasis to-day should be placed rather on the study of its application. Although the most efficient source possible as a result of the evolution of scientific research may not yet have been developed, numerous sources are available which have not been utilized to the limit of their possibilities. Until the fundamental or auxiliary sciences,—if we may speak of them as such—which underlie the science of illuminating engineering attain to perfection that science cannot be perfect, but the development of the science of illuminating engineering is not abreast of those auxiliary sciences on which in large part it depends.

What is the present status of illuminating engineering considered as a distinct science? I regret the necessity of a confession to a relatively low stage of development. In interior lighting, for example, we base our calculations on the horizontal illumination on a plane thirty inches above the floor, and most of us at some times, and some of us at most times, make the implicit

assumption that the aim of the lighting installation is to produce a *uniform* distribution of illumination over this imaginary test plane. There is little knowledge at present of the proportion of luminous flux that should fall on the walls and ceiling compared with that which should be directed upon the arbitrary test plane; there is little attention given to the illumination intensity on vertical and inclined planes at different angles, and in different parts of the room. Our knowledge is relatively meagre on the values of high lights and shadows, of directed and diffused illumination. Most of us would be greatly surprised at the results which would be obtained if at some point in a cheerful, sunlit living room the illumination intensity in every direction in space was measured by pointing the test screen of an illuminometer successively in all directions. Our knowledge of exact conditions in those cases of daylight illumination which are generally recognized as highly satisfactory, is very deficient, and the result must follow that with less satisfactory illuminants and with imperfect knowledge our attempts at artificial reproduction of these daylight standards meet with but a small measure of success. Illuminating engineering, as a distinct science, is not abreast of those auxiliary sciences on which in large part it depends. To an even greater degree it may be said that the art of illuminating engineering is not abreast of the development of the material illuminants which it applies. The object of the apparently prolonged discussion of the light sources in the preceding paragraphs, was not, as might at first appear, to emphasize the importance of the development of the illuminant, but rather to show the very indefiniteness of our conception of ideality in what might seem to be the simplest and most advanced element of illuminating engineering, and to indicate the complexity of a detailed consideration of each of the many elements, which, taken together, constitute illuminating engineering.

The development of an ideal illuminant is but the pursuance of a single path of the many which converge toward the goal of illuminating engineering, and since, continuing the figure, a single path cannot converge, so the very conception of an ideal illuminant must depend upon the concomitant developments of the correlated sciences and arts. If the development of the physiology and psychology of seeing keeps pace with the pro-

gress of the illuminant and its auxiliary parts, if the dictates of aesthetics are accorded the properly proportioned recognition, and if the resultant quasi-established rules of any stage of development are tested in the workshop of experience, there will be a concordant progress along all of the convergent paths toward the goal.

Illuminating engineering is truly complex, the paths which converge toward its goal are numerous and varied. The consistent and coordinate development along each path as a result of imagination and industry coupled with discretion, will determine the rate of progress toward the goal. What is the goal of illuminating engineering? It is not the mere computation of foot-candle illumination necessary for vision, the design and application of lamps and reflectors which will give a uniform or non-uniform distribution of illumination as the exigencies of the case or the whims of the designer may dictate; it is not the cold, calculated plan of illumination which keeps within the bounds of economy, and does not trespass upon those fields implanted by physiological research with the warning sign of "Dangerous." The goal of illuminating engineering will have been attained when as a result of the concomitant development of its component elements, it will be possible in every case presented, to design a lighting installation which will be efficient, effective, artistic; which will produce an illumination correct in quantity and quality, properly balanced as to high-light and shadow, restful to the eye and harmonious with the form and color schemes involved; which will stand the rigorous test of logical analysis and will appeal to the most highly developed sense of beauty. The goal of illuminating engineering is the attainment to the ideal application of perfect knowledge.

In selecting as the title of this year's presidential address "The Goal of Illuminating Engineering" I was not unmindful of the apparent magnitude of the assumed task or of the natural obstacles in the way of its accomplishment. The idea, however, of attempting to present the specifications of ideal illumination in any or all cases was farthest from my mind. The object of this brief address has been to suggest rather than specify, to exalt the ideals of illuminating engineering rather than to indicate the achievements of the perfected science.

AN UNRECOGNIZED ASPECT OF STREET ILLUMINATION.[1]

BY PRESTON S. MILLAR.

In all available literature of street illumination, however diverse the view points or the conclusions, there is substantial unanimity in restricting discussion to questions of light emanating from lamps and light impinging upon surfaces. Discussions of the use made of the light, of its effectiveness in promoting discernment of objects, and of questions of discernment are rare. It is the purpose of this paper to call attention to an obvious method of discernment which has failed to receive due attention from those who have discussed the subject.

PURPOSES OF STREET LIGHTING.

What are the chief purposes to be served in street lighting? Let us consider some representative cases.

Vehicle.—It is of first importance that its presence be detected and its location determined. It may be desirable to learn its color, character, etc., but these considerations are not of first importance. Their desirability varies with the prominence and importance of the thoroughfare.

Pedestrian.—It is of first importance that his presence be detected and his position located. If the illumination will also reveal his features a requirement of the highest class of street lighting is met, but this is usually of minor importance.

Small Obstruction.—When approaching a small object in the street it is desirable to know whether it is a stone or a tin can but the most important purpose is served if the object is seen and avoided.

Hole in Street Surface.—A dark area on the street surface may be moisture or a hole. If the illumination at all times makes the irregularity apparent we must be content in the present state of the art.

From the above the conclusion is reached that the most im-

[1] A paper presented before the New York Section of the Illuminating Engineering Society, October 13, 1910.

portant purposes to be served in street illumination are: First, detection of the presence of objects on the street; and, second, detection of surface irregularities. These requirements are fundamentally important, and set a standard of achievement for most contemporaneous installations, representing all that can be expected. As the standard of expenditure for street lighting is raised and more pretentious lighting is attempted other secondary requirements claim consideration.

DISCERNMENT OF SURFACE IRREGULARITIES.

Surface irregularities are perceived because some portion of the

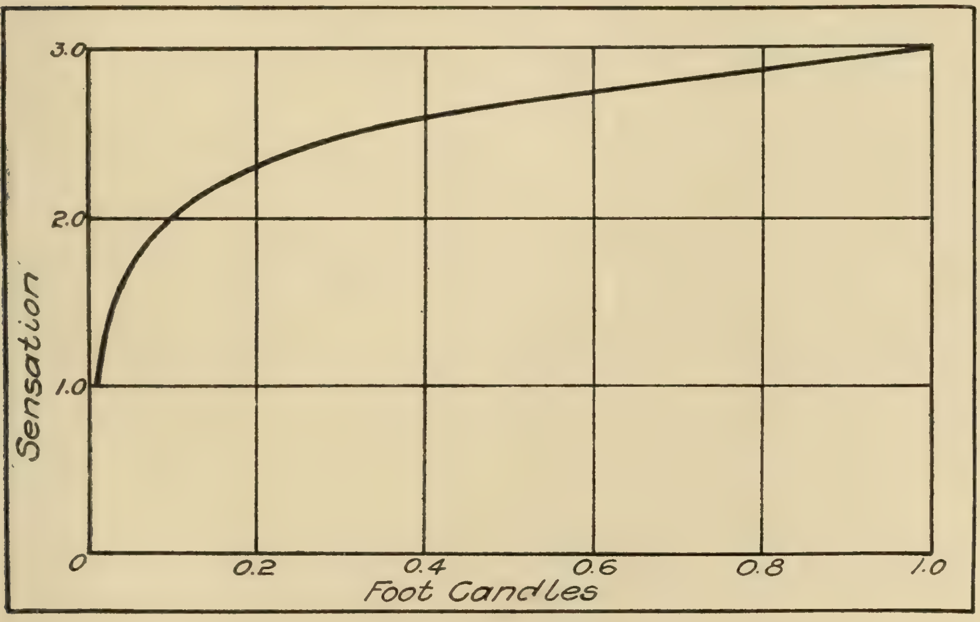


Fig. 1.—Logarithmic curve based on sensation at 0.01 foot-candle.

irregular surface is brighter or darker than the immediate surrounding surface. Ability to see such irregularities depends largely upon the intensity of the illumination in the immediate locality. We discern a stone if there is enough light falling in its immediate neighborhood either to render its observed surface brighter than the surrounding area, or to render the surrounding surface bright, while leaving the observed surface of the stone unilluminated and causing a shadow on the street surface. In either event, there must be enough light to make the contrast noticeable. There is a certain minimum intensity below which a given contrast under a given condition cannot be distinguished.

With increasing intensity one is believed to see more and more readily as indicated in Fig. 1, which is plotted from Fechner's Law of Sensations.

The question of discernment of surface irregularities is an important part of the problem of street illumination. The great mass of the literature of street lighting, as far as it deals with the subject of illumination, deals only with this phase of discernment, considering only the light impinging upon an object, when discussing its visibility.

DISCERNMENT OF LARGER OBJECTS.

The percepton of small objects on the surface of the street and the detection of irregularities in the street surface are purposes which must be served by any effective street lighting installation, but any estimation of the effectiveness of an installation is likely to fall short of correctness if these are the only factors considered. The discernment of larger objects on the street, such as pedestrians and vehicles, is of at least equal importance, and in the discernment of such objects other factors than those already discussed must be considered.

The light incident upon the near surface of a large body, such as a pedestrian, is either sufficient, or too feeble to render him visible. If sufficient, the pedestrian can, of course, be seen; if too feeble to make him visible, it does not follow that he cannot be seen, because in most street lighting installations, the incident light does not form an adequate criterion of the conditions of discernment of large objects. It may even occur that with decreased intensity of light upon the object it may be discerned more clearly, and, conversely, that with increased intensity of light upon the object it may be discerned less clearly. For example, in a particular instance a pedestrian wearing clothes of substantially the same light-reflecting power as the street surface, is seen by reason of the light falling upon him when he is near a lamp; but he is barely discernible when, in walking along the street, he reaches a locality in which the light reflected from his clothing is about the same as the light reflected from the street which serves as a background against which he is viewed. As he proceeds along the street away from the observer and from the nearest lamp, the light falling upon

him becomes less intense, and he would be less easily discernable if dependence were placed alone upon incident light. As a matter of fact, the pedestrian is more easily perceived than when near the lamp, because, as less light is reflected from him to the observer he becomes more darkly *silhouetted against the background* which is chiefly the street at a distance. In street lighting, as a rule, large objects on the street are seen as silhouettes.

Fig. 2 is an illustration of such discernment. The automo-

Fig. 2.—Discernment by silhouetting.[1]

bile shown was 300 ft. (approximately 91 meters) from the camera and nearly 200 ft. (approximately 60 meters) from the intermediate lamp. If one had to rely upon the light falling upon the automobile, discernment would be out of the question, but the relatively bright street surface which serves as a background makes it easily visible even with the small flux of light there available.

In the photograph one detects the presence of an object because portions of the brightly-lighted street surface and trees

[1] Taken for the author by the photographic department of the New York Edison Co.

are obscured. The outline of the obscuring object is recognized as that of an automobile. The presence of the automobile is apparent not because one sees it but because one fails to see the lighted background, within the outline of the object. The phenomenon is simply an eclipse.

This process of discernment is, in the writer's opinion, the most usual and the most important in street illumination. It depends upon a contrast between the object to be discerned and the background, which is usually a street surface, at a distance of from 1/16 to ¼ mile (approximately 100 to 400 meters). Naturally the only factor which is here under control is the brightness of the background. As most objects to be discerned are dark either by reason of low light-reflecting power or low intensity of light falling upon them, it follows that most objects of this nature may be discerned more readily as the background is made brighter.

It is important to remember that it is the distant lamps which determine the brightness of this background. Put out the distant lamps which affect the illumination in the observer's vicinity inappreciably, and immediately discernment of nearby objects on the street is rendered more difficult.

A fact which has great influence upon street illumination is that within wide limits the apparent brightness of a surface is independent of the distance between that surface and the observer. Other things being equal, the street surface ¼ mile (400 m.) from the observer appears substantially as bright as it would if observed from a distance of 1/16 mile (100 m.) and from the same angle. It is very important to consider this fact when studying the influence of distant parts of the street upon the discernment of nearby objects. In order to see a vehicle or pedestrian in the street, it is necessary only to provide a substantially bright street and the distance of the street surface background from an observer is immaterial, within wide limits.

Imagine a street which ends abruptly at a distance of ¼ mile (400 meters) at the edge of a field. One way to make large objects on that street discernible when looking toward the end of the street, would be to erect a board fence across the end of the street, paint the fence white and illuminate it brightly.

In the ordinary street the distant surface is the equivalent of such a fence.

CONCLUSIONS.

The perception of large objects in the street is accomplished by the aid of light falling upon the objects when they are in the immediate vicinity of a lamp, and elsewhere when for some reason or other there is no bright background against which they may be contrasted. Most frequently, however, they appear silhouetted against a lighted background. As the discernment of large objects is in some cases the most important, and in all cases an important, purpose to be achieved, this is one of the essential elements of the problem of street lighting. Having failed to receive due recognition, it affords a new viewpoint from which to consider the whole subject. The writer hopes at an early date to present before this Society supplementary considerations which this point of view adds to discussions of such aspects of the problem, as, light distribution, uniformity, glare, test criteria, etc.

DISCUSSION BY NEW YORK SECTION.

Dr. C. H. Sharp:—The author has directed attention to the importance of illuminating the roadway so as to enable objects on the roadway to be perceived. When use is made of proper reflectors placed upon lamps mounted at the proper height so as to illuminate the roadway correctly, objects are seen silhouetted against the lighted background as described by the author. A street may be excellently lighted in this manner.

W. H. Gardiner:—Street lighting may be divided into three general classes. The first is the mere marking of the way so that a person may be able to follow the route. The second is the silhouetting method, which is much better than the first, and is probably the best that can be obtained for the money invested. However, in this case the streets are merely lighted, there being no real street illumination. The third class is street illumination. In the use of lamps on posts along the street, street lighting committees are apt to think that just because there have been installed certain ornamental posts with decorative lamps the streets are being lighted. Unless properly designed, the last

form of lighting may be just as inferior from some points of view as the first two classes. What is really desired is a decorative form of lighting which will thoroughly and efficiently illuminate the streets without introducing objectionable physiological factors. That is to say, illuminating the street is a very different matter from merely putting lamps along the route.

Mr. V. R. Lansingh:—The author's idea as regards silhouetting is very clever. The silhouetting effect can be rendered more apparent in street lighting by eliminating glare, in which event vehicles stand out more prominently against the lighted street as a background.

PUBLIC SCHOOL ROOM LIGHTING.[1]

BY GEORGE W. KNIGHT AND ALBERT JACKSON MARSHALL.

The authors herewith present the results of a number of tests conducted for the Board of Education, Newark, New Jersey, at the Burnett Street Public School, for the purpose of determining the most desirable lighting system for employment in class rooms in public schools in the aforementioned city. The first tests were made June 17, 1908, between the hours of 8:00 and 10:30 p. m. Further tests were made on the evenings of January 8, and February 1, 1909, between the same hours. In all, nine kinds and arrangements of illuminants were tested. The purpose of each test was to determine the average intensity of illumination, over the desk area, and the maximum variation from this average. In the first tests, two rooms were used, each of the dimensions; length, 32′ 0″; width 24′ 0″; height 12′ 3″. Ceiling and parts of side walls, not taken up by windows or blackboards, white plaster, woodwork, light oak. Six (6) outlets were available; four (4) being in the form of a rectangle, one in the center of the room, and one at one end of the room over the teacher's desk. The exact location of these outlets is shown in Fig. 1.

In making this test the following method was employed. The northwest quarter of the room was divided into twelve squares, each 4′ 0″ to the side. An illuminometer reading was taken at each test, in the center of each square, and the average of these twelve readings was considered the average illumination in the room. Readings were taken at the height of the desks above the floor which is 2′ 3″. In order to determine the maximum variation from the mean illumination, additional readings were taken directly under the outlet included within this quarter of the room and directly under the outlet in the center of the room. An additional reading was taken in the center of the

[1] A paper presented at a meeting of the New York Section of the Illuminating Engineering Society, New York, February 17, 1910.

teacher's desk which is 2′ 6″ above the floor. Due to the fact that the central outlet was 0′ 6″ back of the center of the room, a strip at the forward edge of the room 0′ 6″ in width was neg-

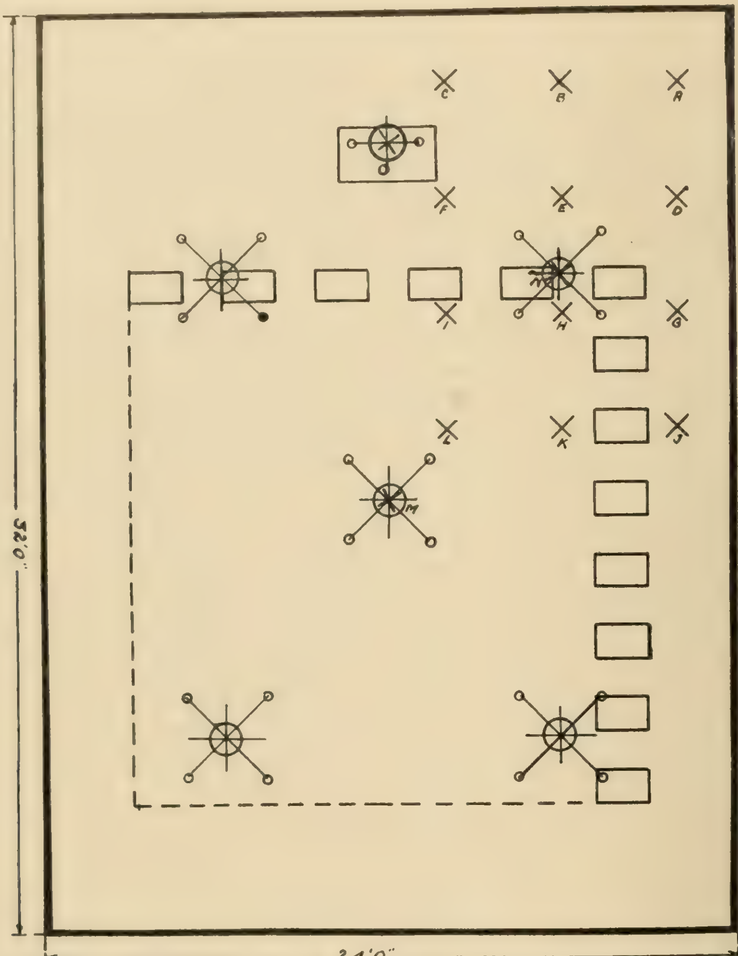


Fig. 1.—Locations of outlets.

lected, thus bringing the first row of stations 2′ 6″ from the front of room instead of 2′ 0″.

Alternating current of 60 cycles was used, and the voltage varied during the test from 120 to 123.3.

As a wattmeter was not available wattage readings were taken with an ammeter and voltmeter. Since we were not aware of any inductive load the power factor was assumed to be unity or nearly such.

Illumination readings were made with an illuminometer. The test lamp was 120 volts, standardized for the instrument, and was maintained at its proper voltage by means of a rheostat forming a part of the instrument and a voltmeter. The voltmeter used was a combined alternating-current and direct-current instrument. The same instrument was used for reading both the line voltage, and the voltage on the standard lamp. Wattage read-

Fig. 2.—General view of equipment.

ings were taken by the same instrument used in connection with an alternating-current ammeter.

Three schemes of illumination in the first series were considered:—

1. The lighting equipment, which at the time of the test was in use, consisted of five 4-lamp chandeliers and one 2-lamp chandelier, the latter being over the teacher's desk. Each illuminant consisted of one 16 c-p. clear, carbon filament lamp, and 8½″ flat white porcelain reflector with 2¼″ holder.

The bottom of the lamp came to a point 6′ 10″ above the floor. On the 4-lamp fixtures, the spread was 4′ 0″, the arms being at an angle of 45 degrees from a line parallel to side walls. The spread of the chandelier over the teacher's desk was 2′ 8″, arms running with width of room. This equipment is shown by photographic view of room as indicated by Fig. 2.

The following is the result of Test No. 1, the arrangement of which is indicated by Fig. 1.

1. Five 4-lamp chandeliers and one 2-lamp chandelier, each lamp consisting of a 16 c-p., 115 volt, clear, carbon-filament lamp and 8½″ flat white porcelain reflector with standard 2¼″ holder.

Height of room	12′ 3″
Height of desks	2′ 3″
Height to bottom of lamp	6′ 10″
Height of lamp above plane of illumination	4′ 7″
Spread of 4-lamp fixtures	4′ 0″
Spread of 2-lamp fixtures	2′ 8″

	Volts	Amp.	Watts	Watts corrected for rated voltage
Circuit No. 1—Two 4-lamp fixtures and one 2-lamp fixture	122	4.42	539.2	471.1
Circuit No. 2—Three 4-light fixtures	121	5.36	648.6	581.6
Total watts				1053.3
Watts per lamp				47.9

Station	Volts	Reading foot-candles	Mean foot-candles	Mean corrected for rated voltage
		1.45		
A	120.5	1.40	1.43	1.12
		1.43		
		2.00		
B	120.0	2.15	2.10	1.67
		2.15		
		3.20		
C	120.5	3.10	3.17	2.48
		3.20		
		2.20		
D	120.5	2.20	2.22	1.66
		2.25		
		4.20		

Station	Volts	Reading foot-candles	Mean foot-candles	Mean corrected for rated voltage
E	120.0	4.10	4.13	3.28
		4.10		
		4.60		
F	120.5	4.70	4.60	3.60
		4.50		
		2.60		
G	120.5	2.60	2.57	2.01
		2.50		
		4.70		
H	120.5	4.80	4.73	3.69
		4.70		
		5.0		
I	121.0	5.0	5.00	3.82
		5.0		
		2.00		
J	120.5	2.10	2.03	1.59
		2.00		
		3.10		
K	120.5	2.90	2.90	2.26
		2.70		
		5.00		
L	121.0	5.10	5.03	3.84
		5.00		
		6.00		
M	120.0	6.10	6.10	4.84
		6.20		
		5.00		
O	120.0	5.00	4.97	3.94
		4.90		

Mean foot-candles throughout room, 2.59.
Mean foot-candles on desks, 3.42.
Maximum variation from mean throughout room, +86.9%.
Maximum variation from mean on desks, +33.9%.
Maximum variation at station M in each case.

2. Five 75 c-p., frosted tip graphitized-filament lamps with prismatic bowl reflectors with light interior enamel. The photometric curve of the lighting unit is shown in Fig. 3.

The bottom of lamp came to a point 6′ 10″ above the floor. The locations of the lighting units are showin by Fig. 4.

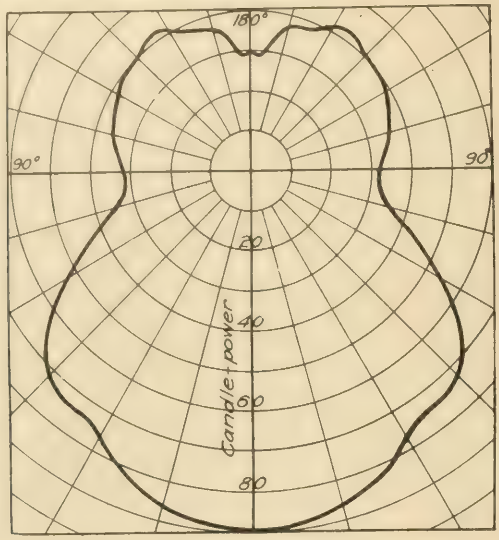


Fig. 3.—Light distribution about a 187-watt graphitized-filament lamp equipped with a prismatic bowl reflector with light interior enamel.

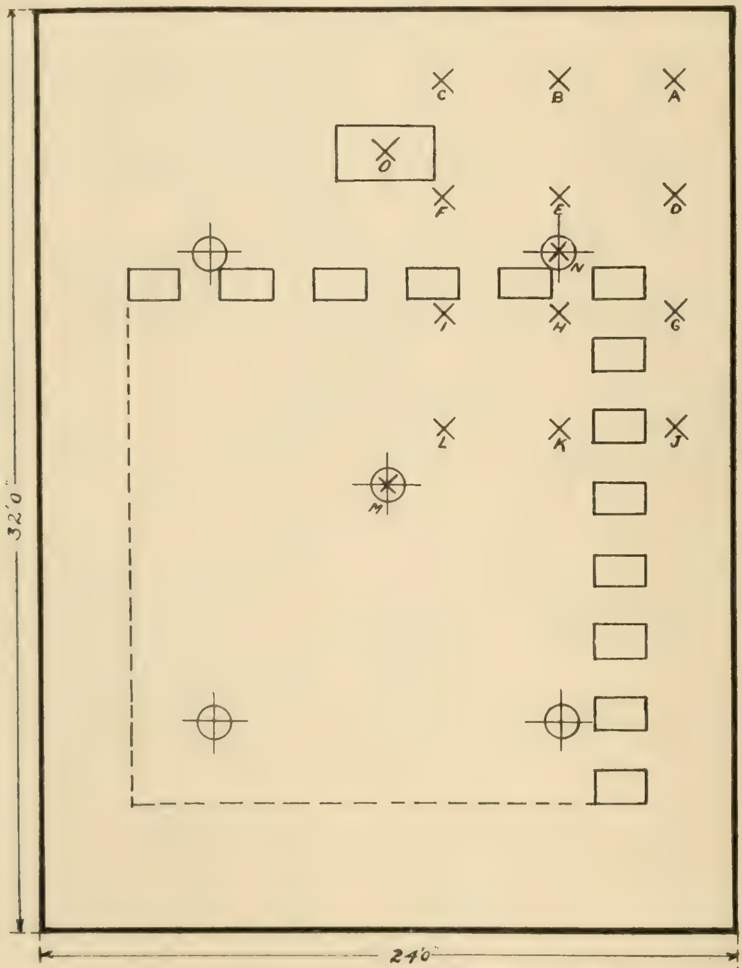


Fig. 4.—Locations of lighting units.

2. 5-115 volt, 187 watt, 75 c-p., frosted tip graphitized-filament lamps with prismatic bowl reflectors with light interior enamel. The photometric curve is shown in Fig. 3.

Ceiling height	12′	3″
Desk height	2′	3″
Height to bottom of lamp	10′	3″
Height of lamp above plane of illumination	8′	0″

	Volts	Amp.	Watts	Watts corrected for rated voltage
Circuit No. 1—2 lamps	124.5	3.30	410.9	354.3
Circuit No. 2—3 lamps	122.0	4.95	603.9	539.2
Total watts				893.5
Watts per lamp				177.4

Station	Volts	Reading foot-candles	Mean foot-candles	Mean corrected for rated voltage
		1.70		
A	120.0	1.70	1.72	1.40
		1.75		
		2.20		
B	120.0	2.20	2.18	1.77
		2.15		
		2.25		
C	120.5	2.10	2.15	1.71
		2.10		
		2.10		
D	120.5	2.20	2.17	1.72
		2.20		
		3.20		
E	121.0	3.40	3.30	2.58
		3.30		
		3.20		
F	120.5	3.20	3.27	2.60
		3.30		
		2.40		
G	120.5	2.50	2.47	1.96
		2.50		
		3.50		
H	120.5	3.70	3.57	2.84
		3.50		
		3.90		
I	120.5	3.80	3.83	3.04
		3.80		

Station	Volts	Reading foot-candles	Mean foot-candles	Mean corrected for rated voltage
		2.10		
J	120.5	2.20	2.13	1.69
		2.10		
		3.00		
K	120.5	2.80	2.87	2.28
		2.80		
		3.90		
L	120.5	3.90	3.90	3.10
		3.90		
		4.20		
M	120.5	4.30	4.30	3.41
		4.40		
		3.70		
N	120.5	3.70	3.70	2.94
		3.70		
		3.00		
O	120.5	2.90	2.93	3.32
		2.90		

Mean foot-candles throughout room, 2.22.
Mean foot-candles on desks, 2.74.
Maximum variation from mean throughout room, +53.6%.
Maximum variation from mean on desks, +24.4%.
Maximum variation at station M in each case.

This equipment is shown by photographic view of room which follows.

3. Five 100-watt lamps with light frosted tip tungsten lamps and prismatic bowl reflectors, interior enamel. Bottom of lamp came to a point 10′ 3″ above the floor. For location of lighting units see Fig. 1. Fig. 5, which is a view of this room when arrangement number 2 was being tested, will give quite a clear idea of the appearance of arrangement number 3. For photometric curve see Fig. 6.

3. Five 115 volt, 100-watt, 80 c-p., frosted tip, tungsten lamps with prismatic inverted bowl reflectors with light interior enamel.

Ceiling height	12′	3″
Desk height	2′	3″
Height to bottom of lamp	10′	3″
Height of lamp above plane of illumination	8′	0″

Fig. 5.—General view of equipment.

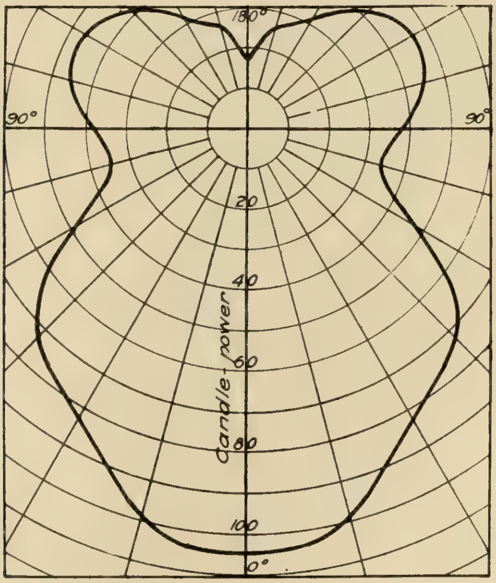


Fig. 6.—Distribution of light about a 100-watt bowl-frosted tungsten lamp equipped with a prismatic bowl reflector with light interior enamel.

	Volts	Amp.	Watts	Watts corrected for rated voltage
Circuit No. 1—2 lamps	121.0	1.50	181.5	167.2
Circuit No. 2—3 lamps	120.5	2.45	295.5	274.1
Total watts				441.3
Watts per lamp				88.3

Station	Volts	Reading foot-candles	Mean foot-candles	Mean corrected for rated voltage
A	121.5	2.50 2.25 2.40	2.57	2.10
B	121.3	2.80 3.00 2.90	2.90	2.39
C	121.5	3.10 3.00 3.10	3.03	2.47
D	121.5	3.10 3.00 3.10	3.07	2.51
E	121.7	4.70 4.80 4.60	4.70	3.83
F	122.3	4.40 4.50 4.40	4.43	3.53
G	122.4	3.50 3.40 3.50	3.47	2.78
H	123.0	5.00 5.10 5.20	5.10	3.98
I	121.0	5.20 5.10 4.90	5.07	4.22
J	122.5	3.00 3.00 3.00	3.00	2.38
K	123.3	4.10 3.90 4.00	4.00	3.08
L	120.6	5.40 5.40 5.60	5.47	4.63

Station	Volts	Reading foot-candles	Mean foot-candles	Mean corrected for rated voltage
		6.00		
M	120.6	5.80	5.87	4.97
		5.80		
		5.40		
N	122.2	5.40	5.40	4.35
		5.40		
		4.00		
O	121.3	3.90	3.97	3.27
		4.00		

Mean foot-candles throughout room, 3.16.
Mean foot-candles on desks, 3.88.
Maximum variation from mean throughout room, +57.3%.
Maximum variation from mean on desks, +28.1%.
Maximum variation at station M in each case.

COMPARISON OF THREE SYSTEMS.

	Mean foot-candles	Total Watts
System No. 2—75 c.p. gem lamps	2.74	893.5
System No. 3—100-watt tungsten lamps	3.88	441.3
System No. 1—16 c.p. carbon lamps	3.42	1053.3

CORRECTIONS.

Assuming the instruments used to be correct, the only correction necessary is that for the voltage supplied the lamps. Since the illumination will increase directly in proportion to the increase in the candle-power of the lamps, the illumination readings may be corrected for the candle-power which the lamps would give at rated voltage. These corrections have been made, using reliable voltage candle-power characteristic curves for the various types of lamps used.

Correction for the wattage readings obtained were made from the characteristic voltage-wattage curve of each type of lamp. These curves were obtained from the same source as the voltage candle-power curve.

COMMENT ON METHOD OF FIGURING.

In obtaining the average or mean foot-candles throughout the room, all points except M, N and O were considered. Readings were taken at the points M and N only because these points were likely to be points of maximum intensity. Readings were

taken at the point O only to show the illumination on the teacher's desk.

While the value of mean foot-candles on desks is nearly correct, it cannot be taken as absolutely accurate for this reason: The points considered were E, F, H, I, K and L. The average of these points should give the average of the area comprising the squares of which each is the center. The area including the desks is slightly larger than this area. At the back of the room and at the front of the room the desks came well within the area considered. On the sides, however, the outer edge of the desks is 9-inches outside of the area considered.

CONSIDERATION OF SYSTEM NO. 1.

16 c.p. carbon-filament lamps.

This system should be rejected for three reasons:—

1. The effect of the lighting system as a whole is injurious to the eyes of the pupils. The lamps are less than 7′ 0″ above the floor and come directly within the range of vision. The lamps are clear and the reflector used does not hide any portion of the filament.

2. The cost of operation of this system is excessive. One outlet more than in the other systems is used, thereby causing a higher cost for wiring.

3. The illumination from system No. 2 is inferior to that obtained from No. 3 and No. 1. Comparing system No. 1 with system No. 2, the former shows 3.42 foot-candles on the desk, while the latter shows 2.74. It is probable, however, that the effective illumination is very nearly the same in the two cases This is due to the fact that the eye adjusts itself to the brilliancy of the light sources within the range of vision. With the bare filament in the range of vision, the aperture of the eye becomes smaller, thus allowing less light to effect the retina than would be the case were the light sources absent. The illumination therefore, appears less brilliant than it really is. A rough comparison by the eye of the two systems shows this to be correct, and if any difference in illumination were noticed, it would be in favor of system No. 2.

COMPARISON OF SYSTEMS NOS. 1, 2 AND 3.

Systems Nos. 2 and 3 are both superior to system No. 1, but of the two, system No. 3 has the following advantages.

1. The cost of maintenance of system No. 2 is in excess of system No. 3.

2. The illumination obtained from system No. 3 is 42 per cent. higher than that obtained from system No. 2. This is true of the effective illumination, as well as the actual illumination since the light sources are placed at the same height in each case, and are well above the range of vision, with the brilliancy of the light sources, approximately the same for both systems. Illuminometer readings were made by Albert J. Marshall, voltmeter readings by C. E. Scribner and F. W. Loomis, voltmeter and ammeter readings for wattage by Albert J. Marshall, and all readings were registered by T. W. Rolph.

SECOND SERIES OF TESTS.

In the tests of January 28 and February 1, 1909, one of the two rooms as previously described, was used. On these two evenings eight tests were made. For convenience in changing from one system to another, parallel copper wires were stretched across the room close to the ceiling. Wooden rods were placed behind these wires at right angles to them, and arranged to slide in a direction parallel to the wires. The lamps were connected to the ceiling outlets by flexible cords, which were passed through a ring on the wooden rods so that the units could be moved along the wires or rod or placed at any desired height.

INSTRUMENTS.

The illuminometer used was a Sharp-Millar photometer. The standard lamp was a battery lamp operated by three dry cells and maintained at its proper amperage by means of a rheostat and millivoltmeter. The voltmeter used was a combined direct-current and alternating-current instument with its multiplier. Wattage readings were taken with the same voltmeter used in connection with an alternating-current ammeter.

METHOD OF TEST.

The lamps were arranged according to the scheme to be

used. The different arrangements are shown on accompanying plans. The desks were numbered and illuminometer readings were taken at the center of each desk. The construction of the illuminometer necessitated taking each reading at a point 6½″ above the level of the desk, making the plane of readings 2′ 7½″ above the floor. The distance of the lamps above the plane of readings is the most important consideration, however.

The current supplied was alternating current, 60 cycles, and the voltage varied during the tests from 117.9 to 123.5.

As a wattmeter was not available, wattage was obtained by means of ammeter and voltmeter readings. The power factor is assumed to be unity, since the presence of inductive load on the circuit is improbable.

CORRECTIONS.

After the test, the lamp and photometer were calibrated at the Electrical Testing Laboratories, readings being taken by Mr. Rolph who took the readings during the tests. A correction factor was obtained of 1.51 which was applied to the readings as taken. The other instruments used were recently calibrated and, therefore, assumed to be correct. The only other correction necessary is that for the voltage supplied to the lamp. Since the illumination will vary directly in proportion to the variation in the candle-power of the lamps, the illumination readings may be corrected for the candle-power which the lamps would give at rated voltage. Assuming that the lamps used were rated correctly, these corrections have been made, using reliable voltage candle-power characteristic curves for the various types of lamps used. The wattage readings were similarly corrected for rated voltage.

METHOD OF FIGURING.

The illumination at the center of each desk is assumed to be the average illumination for that desk. The average illumination over the desk area is, therefore, the average of the values obtained on all the desks.

In tests No. 3 and No. 6 readings were taken over the back half of the room only. In test No. 3 the same equipment, height and spacing were used as in test No. 2, with each unit moved 1′ 6″ to the left of its position in test No. 2. The ratio of mean foot-

candles over the back of the room to those over the front of the room in test No. 2 was found. This ratio is assumed to be true for test No. 3 and was used to obtain the average intensity over the desk area for that test. The same process of figuring was

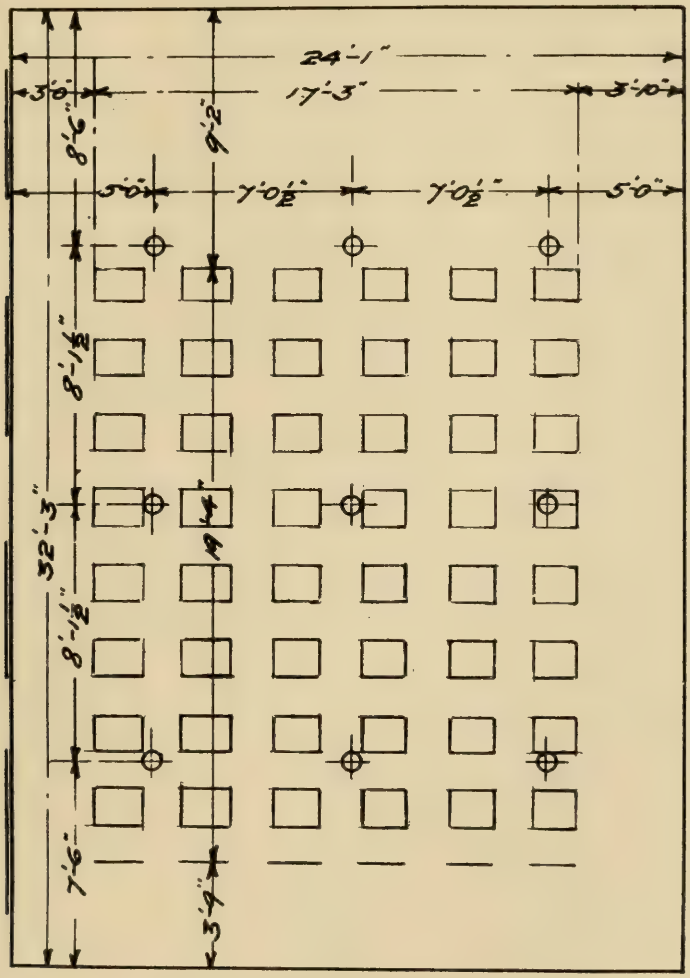


Fig. 7.—Locations of lighting units.

used for test No. 6 in connection with test No. 5, as the equipment, height and spacing of the units were the same except that in test No. 6 the lamps were moved 1′ 6″ to left of their position in test No. 5.

In reducing the illumination to equivalent wattage for comparison, the wattage in each case is taken as rated wattage of the lamp.

TEST NO. 1.

Fig. 7 shows location of light sources.

Nine-lamp scheme, lamps arranged symmetrically. Each unit consisted of one 115-volt, 100-watt, 40 c-p., bowl-frosted graphitized-filament lamp and prismatic bowl reflector with enamelled

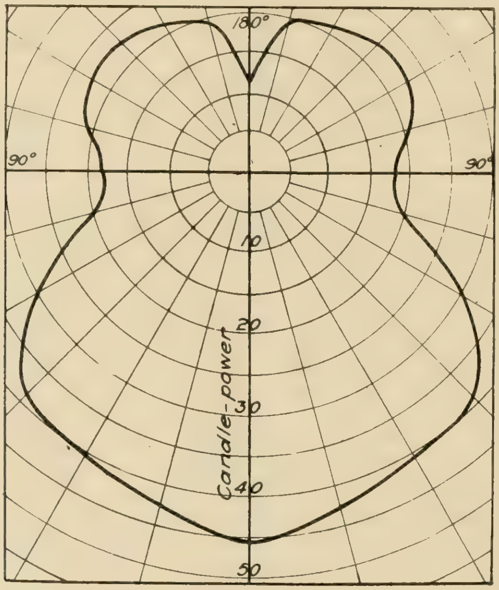


Fig. 8.—Photometric curve for 100-watt bowl frosted graphitized-filament lamp equipped with a prismatic bowl reflector with light interior enamel.

interior, giving the photometric curve shown in Fig. 8.

Bottom of lamp come to a point 7′ 7½″ above plane of readings.

	Volts	Amp.	Watts	Watts corrected for rated voltage
Circuit No. 1—3 lamps	118.6	2.70	320	302
Circuit No. 2—6 lamps	118.9	5.20	623	589
Total watts				891
Watts per lamp				99

Station	Line voltage	Illumination foot-candles as read	Illumination foot candles corrected for illuminometer calibration	Illumination foot-candles corrected for rated voltage and average per station
1	121.0	2.12	3.20	2.55
	121.0	2.10	3.17	
2	120.3	2.65	4.00	3.28
	120.3	2.62	3.98	
3	120.6	2.38	3.60	2.90
	120.5	2.37	3.58	
4	120.6	2.36	3.56	2.88
	120.8	2.37	3.58	

Station	Line voltage	Illumination foot-candles as read	Illumination foot-candles corrected for illuminometer calibration	Illumination foot-candles corrected for rated voltage and average per station
5	120.5	2.15	3.25	2.63
6	120.4	2.60	3.92	3.17
7	120.2	2.59	3.91	3.20
8	120.3	2.67	4.03	3.29
9	120.2	2.28	3.44	2.82
10	120.0	2.75	4.16	3.44
11	120.7	2.63	3.97	3.20
12	120.7	2.77	4.18	3.36
13	121.6	2.92	4.41	3.41
14	120.7	2.63	3.97	3.20
15	120.8	2.41	3.64	2.93
16	120.7	2.56	3.86	3.11
17	120.6	2.98	4.50	3.62
18	120.9	2.91	4.39	3.53
19	120.3	2.68	4.05	3.31
20	120.8	2.78	4.20	3.38
21	120.5	3.22	4.86	3.94
22	120.3	3.07	4.63	3.79
23	120.7	2.95	4.46	3.60
24	120.7	3.01	4.55	3.67
25	121.5	3.36	5.07	3.94
26	120.0	2.74	4.13	3.43
27	120.2	3.10	4.68	3.82
28	120.0	3.31	5.00	4.15
29	120.0	2.84	4.28	3.56
30	120.2	2.50	3.78	3.10
31	120.0	2.62	3.96	3.28
32	120.2	2.25	3.40	2.78
33	120.3	2.07	3.12	2.55
34	120.3	2.45	3.70	3.02
35	120.6	2.58	3.90	3.14
36	120.7	2.62	3.96	3.18
37	121.2	2.92	4.41	3.52
38	120.6	2.88	4.35	3.50
39	120.7	2.76	4.17	3.35
40	120.8	2.75	4.15	3.35
41	120.4	2.82	4.26	3.46
42	120.7	2.50	3.78	3.04
43	120.7	2.93	4.43	3.56
44	120.6	2.98	4.50	3.62
45	120.8	2.38	3.60	2.90
46	120.8	2.37	3.58	2.88
47	120.8	2.75	4.15	3.35
48	120.8	2.25	3.40	2.73

Not corrected for voltage:

Mean foot-candles 4.05
Mean variation from mean .... 1.02 foot-candles (Station 25)
Maximum variation from mean ..... 25.2 %

Corrected for voltage:

Mean foot-candles 3.29
Maximum variation from mean .... .87 foot-candles (Station 28)
Maximum variation from mean .... 26.4 %

TEST NO. 2.

For location of light sources, see Fig. 7.

Nine-lamp scheme, lamps arranged symmetrically. Each unit consisted of one 115-volt, 100-watt, 40 c-p., bowl-frosted graphitized-filament lamp and prismatic bowl reflector, enamelled interior. Bottom of lamp came to a point 8′ 7½″ above the floor, or 6′ 0″ above plane of readings. Wattage same as Test No. 1. For photometric curve see Fig. 8.

Station	Line voltage	Illumination foot-candles as read	Illumination foot candles corrected for illuminometer calibration	Illumination foot-candles corrected for rated voltage and average per station
1	119.8	1.71	2.58	2.18
2	119.7	2.25	3.40	2.86
3	120.0	2.00	3.02	2.51
4	120.0	2.19	3.31	2.75
5	121.0	1.96	2.96	2.37
6	120.5	2.35	3.55	2.87
7	120.8	2.31	3.49	2.81
8	120.9	2.50	3.78	3.04
9	120.8	2.07	3.12	2.52
10	120.9	2.54	3.84	3.08
11	121.8	2.68	4.05	3.14
12	121.1	2.83	4.27	3.40
13	119.8	2.51	3.79	3.19
14	119.6	2.24	3.38	2.84
15	121.4	2.31	3.49	2.75
16	121.0	2.43	3.67	2.94
17	120.8	2.61	3.94	3.17
18	120.5	2.58	3.90	3.14
19	121.0	2.48	3.74	2.99
20	120.9	2.72	4.11	3.31
21	121.2	3.03	4.58	3.69
22	121.1	2.95	4.46	3.54
23	120.8	2.80	4.23	3.42
24	120.6	2.91	4.40	3.55

Station	Line voltage	Illumination foot-candles as read	Illumination foot-candles corrected for illuminometer calibration	Illumination foot-candles corrected for rated voltage and average per station
25	121.1	3.09	4.67	3.72
26	120.3	2.83	4.27	3.49
27	120.6	3.03	4.58	3.69
28	119.5	3.25	4.91	4.13
29	118.2	2.59	3.91	3.46
30	119.4	2.48	3.75	3.17
31	119.8	2.55	3.85	3.23
32	120.0	2.15	3.25	2.69
33	118.7	1.92	2.90	2.54
34	120.4	2.31	3.49	2.82
35	119.9	2.35	3.55	2.98
36	120.0	2.48	3.74	3.11
37	120.4	2.78	4.20	3.40
38	119.8	2.72	4.11	3.44
39	120.7	2.82	4.26	3.44
40	120.8	3.02	4.56	3.69
41	119.7	2.43	3.67	3.08
42	120.1	2.48	3.74	3.08
43	116.8	2.36	3.56	3.23
44	118.8	2.70	4.08	2.56
45	118.8	2.33	3.52	3.07
46	118.7	2.28	3.44	3.02
47	118.8	2.40	3.62	3.16
48	118.7	1.98	2.99	2.63

Not corrected for voltage:

Mean foot-candles 3.76
Maximum variation from mean ...... 1.18 foot-candles (Station 1)
Maximum variation from mean 31.4%

Corrected for voltage:

Mean foot-candles 3.11
Maximum variation from mean .... 1.02 foot-candles (Station 28)
Maximum variation from mean 32.8%

TEST NO. 3.

For arrangement of light sources, see Fig. 9.

Nine-lamp scheme, lamps moved 1′ 6″ to left of position in Test No. 2. Each unit consisted of one 115-volt, 100-watt, 40-c-p., bowl-frosted graphitized-filament lamp and prismatic bowl reflector with enamelled interior. Bottom of lamp came to a point 8′ 7½″ above floor, or 6′ 0″ above plane of readings. Wattage same as Test No. 1. For photometric curve see Fig. 8.

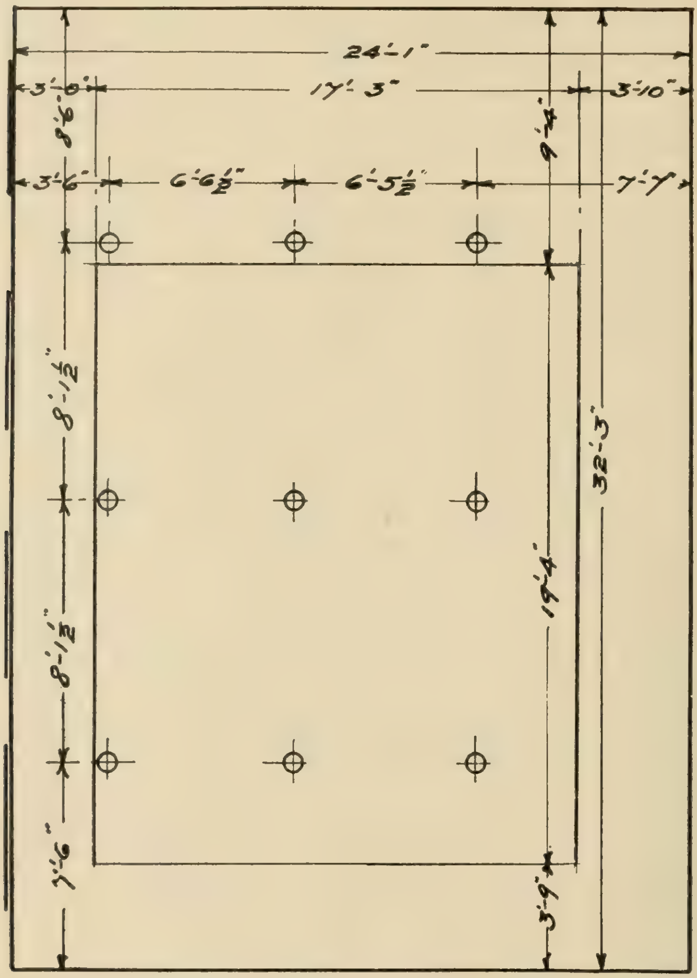


Fig. 9.—Arrangement of lighting units.

Station	Line voltage	Illumination foot-candles as read	Illumination foot-candles corrected for illuminometer calibration	Illumination foot-candles corrected for raied voltage and average per station
1	120.2	2.18	3.29	2.69
2	120.4	2.67	4.03	3.26
3	120.3	2.57	3.88	3.17
4	120.2	2.63	3.97	3.25
5	119.4	2.02	3.05	2.58
6	120.8	2.60	3.92	3.16
7	120.7	2.63	3.97	3.26
8	120.6	2.90	4.38	3.54
9	119.8	2.12	3.20	2.69
10	119.8	2.61	3.94	3.19
11	119.7	2.78	4.20	3.50
12	119.8	3.02	4.56	3.82
29	119.8	2.77	4.18	3.50

Station	Line voltage	Illumination foot-candles as read	Illumination foot candles corrected for illuminometer calibration	Illumination foot-candles corrected for rated voltage and average per station
30	119.6	2.50	3.78	3.17
31	119.7	2.39	3.61	3.04
32	119.4	2.14	3.23	2.73
33	119.6	1.90	2.87	2.42
	119.5	2.41	3.64	
34	119.8	2.51	3.79	3.14
	120.2	2.53	3.82	
35	119.8	2.45	3.70	3.11
36	120.2	2.55	3.85	3.14
45	120.0	1.88	2.84	2.36
46	120.0	1.33	2.01	1.66
47	120.1	1.86	2.81	2.31
48	120.2	1.56	2.36	1.93

Not corrected for voltage:

Mean foot-candles (back half of room) 3.87

Maximum variation from mean (back half of room) ....—1.86 foot-candles (Station 46)

Maximum variation from mean (back half of room) 48.1%

Mean foot-candles (whole room, from ratio of Test No. 2)...... 4.22

Maximum variation from mean (assuming that this occurs in back half of room) ....—2.21 foot-candles

Maximum variation from mean 52.4%

Corrected for voltage:

Mean foot-candles (back half of room 2.94

Maximum variation from mean (back half of room) ....—1.28 foot-candles (Station 46)

Maximum variation from mean (back half of room) 43.6%

Mean foot-candles (whole room, from ratio of Test No. 2) 3.15

Maximum variation from mean (assuming that this occurs in back half of room) ....—1.49

Maximum variation from mean 47.8%

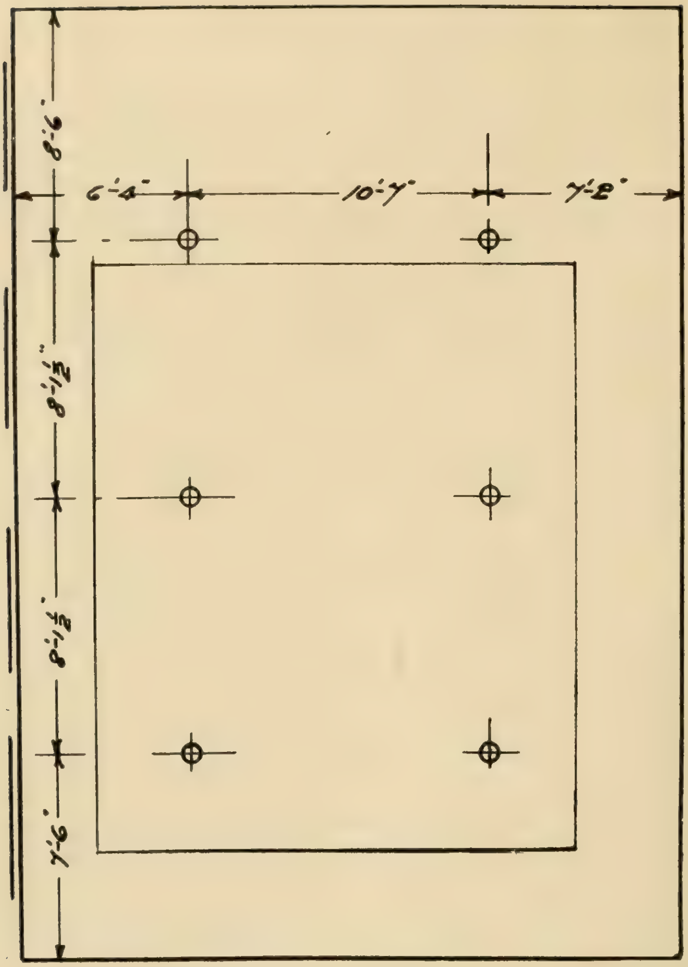


Fig. 10.—Arrangement of outlets.

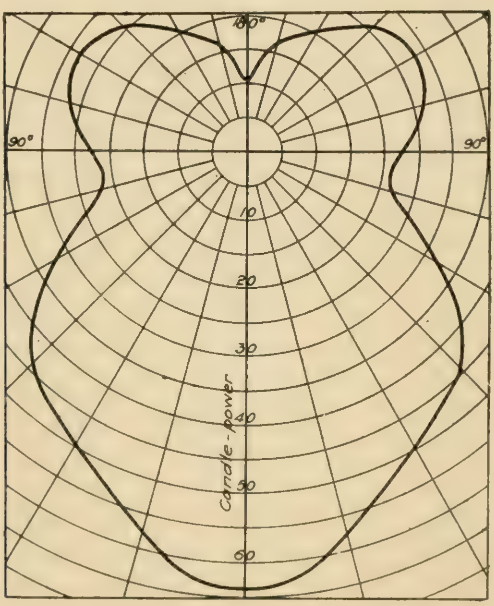


Fig. 11. –Photometric curve of 125-watt bowl-frosted graphitized-filament lamp with prismatic bowl reflector with enamelled interior.

TEST NO. 4.

For arrangement of outlets see Fig. 10.

Six-lamp scheme, lamps arranged symmetrically. Each unit consisted of one 118-volt, 125-watt, 50 c-p., bowl-frosted graphitized-filament lamp and prismatic bowl reflector with enamelled interior. For photometric curve see Fig. 11.

Bottom of lamp came to a point 9′ 7½″ above the floor, or 7′ 0″ above plane of readings.

	Volts	Amp.	Watts	Watts corrected for rated voltage
Circuit No. 1—4 lamps	121.5	4.33	526	500
Circuit No. 2—2 lamps	121.7	2.13	259	245
Total watts				745
Watts per lamp				124

Station	Line voltage	Illumination foot-candles as read	Illumination foot-candles corrected for illuminometer calibration	Illumination foot-candles corrected for rated voltage and average per station
1	121.5	1.53	2.31	2.02
	121.6	1.53	2.31	
2	120.8	1.83	2.76	2.46
	121.1	1.82	2.75	
3	121.4	1.97	2.98	2.52
	121.0	1.81	2.74	
4	120.5	1.81	2.74	2.46
	121.3	1.80	2.72	
5	121.6	1.73	2.61	2.31
	121.5	1.75	2.64	
6	121.8	2.13	3.22	2.87
	121.6	2.20	3.32	
7	121.7	2.31	3.49	2.99
	121.6	2.20	3.32	
8	120.7	2.13	3.32	2.88
	120.9	2.12	3.20	
9	121.4	1.59	2.40	2.14
	121.5	1.63	2.46	
10	121.3	1.87	2.82	2.52
	121.4	1.91	2.88	
11	121.4	2.05	3.10	2.60
	121.5	1.97	2.98	
12	121.3	2.13	3.22	2.86
	121.3	2.12	3.20	
13	121.0	2.00	3.02	2.67
	121.0	1.95	2.94	

Station	Line voltage	Illumination foot-candles as read	Illumination foot-candles corrected for illuminometer calibration	Illumination foot-candles corrected for rated voltage and average per station
14	121.0	1.96	2.96	2.66
	120.8	1.94	2.93	
15	120.8	1.81	2.74	2.45
	120.8	1.78	2.69	
16	120.9	1.86	2.81	2.54
	120.9	1.86	2.81	
17	121.8	2.35	3.55	3.10
	120.9	2.31	3.49	
18	121.2	2.19	3.41	2.94
	121.0	2.17	3.28	
19	121.2	2.15	3.25	2.82
	121.2	2.06	3.11	
20	120.9	2.08	3.14	2.82
	120.5	2.05	3.10	
21	121.8	2.14	3.23	2.81
	121.7	2.12	3.20	
22	121.5	2.12	3.20	2.78
	121.9	2.07	3.12	
23	121.8	2.14	3.23	2.81
	120.9	2.11	3.19	
24	121.2	2.00	3.02	2.75
	121.0	2.08	3.14	

Not corrected for voltage:

Mean foot-candles 3.00
Maximum variation from mean ....— .69 foot-candles (Station 1)
Maximum variation from mean 23.0%

Corrected for voltage:

Mean foot-candles 2.66
Maximum variation from mean ....— .64 foot-candles (Station 1)
Maximum variation 24.1%

TEST NO. 5.

For arrangement of light sources, see Fig. 10.

Six-lamp scheme, lamps arranged symmetrically. Each unit consisted of one 115-volt, 60-watt, bowl-frosted tungsten lamp and prismatic reflector having satin finish. For photometric curve see Fig. 12.

Bottom of lamp came to a point 9′ 7½″ above the floor, or 7′ 0″ above plane of readings.

	Volts	Amp.	Watts	Watts corrected for rated voltage
Circuit No. 1—2 lamps	121.5	1.11	135	124
	121.5	2.01	244	224
Total watts				348
Watts per lamp				58

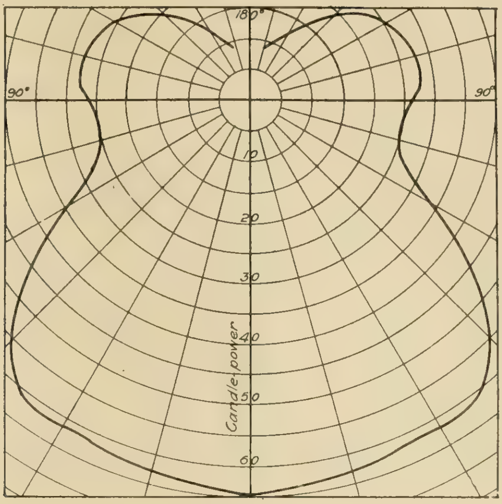


Fig. 12.—Photometric curve of 60-watt bowl-frosted tungsten lamp with prismatic reflector having satin-finish interior.

Station	Line voltage	Illumination foot-candles as read	Illumination foot-candles corrected for illuminometer calibration	Illumination foot-candles corrected for rated voltage and average per station
1	121.9	1.48	2.24	1.90
	122.0	1.63	2.46	
2	122.0	1.92	2.90	2.31
	121.8	1.86	2.81	
3	122.2	2.02	3.05	2.40
	122.2	1.96	2.96	
4	122.2	1.98	2.99	2.48
	121.1	2.10	3.17	
5	121.9	1.91	2.88	2.32
	122.3	1.92	2.90	
6	122.2	2.20	3.32	2.63
	121.9	2.12	3.20	
7	121.6	2.36	3.56	2.93
	121.7	2.40	3.62	
8	122.0	2.35	3.55	2.86
	122.1	2.38	3.60	
9	122.1	1.85	2.80	2.13
	122.0	1.65	2.49	
10	121.9	2.12	3.20	2.54
	121.9	2.03	3.06	
11	121.6	2.17	3.28	2.69
	121.9	2.22	3.36	
12	121.9	2.27	3.43	2.75
	122.0	2.25	3.40	

Station	Line voltage	Illumination foot-candles as read	Illumination foot candles corrected for illuminometer calibration	Illumination foot-candles corrected for rated voltage and average per station
13	122.2	2.25	3.40	2.72
	122.1	2.22	3.36	
14	122.4	2.09	3.16	2.57
	122.4	2.20	3.32	
15	122.6	2.11	3.19	2.52
	122.2	2.09	3.16	
16	123.0	2.14	3.23	2.58
	122.9	2.24	3.38	
17	122.0	2.37	3.58	2.98
	122.2	2.54	3.84	
18	122.2	2.30	3.48	2.82
	122.0	2.35	3.55	
19	122.4	2.35	3.55	2.70
	122.5	2.18	3.29	
20	122.9	2.44	3.68	2.93
	122.8	2.62	3.96	
	122.9	2.35	3.55	
21	122.3	2.37	3.58	2.86
	122.1	2.34	3.53	
22	122.2	2.36	3.56	2.80
	122.0	2.23	3.36	
23	122.2	2.16	3.26	2.63
	122.6	2.20	3.32	
24	122.3	2.12	3.20	2.57
	122.5	2.14	3.23	

Not corrected for voltage:

Mean foot-candles 3.26
Maximum variation from mean ....— .91 foot-candles (Station 1)
Maximum variation from mean 27.9%

Corrected for voltage:

Mean foot-candles 2.61
Maximum variattion from mean ....— .71
Maximum variation from mean 27.2%

TEST NO. 6.

For arrangement of light sources, see Fig. 13.

Six-lamp scheme, lamps moved over 1′ 6″ to left of position in Test No. 5. Each unit consisted of one 115 volt, 60 watt, bowl-frosted tungsten lamp and prismatic reflector with satin finish. Bottom of lamp came to a point 9′ 7½″ above the floor, or 7′ 0″ above plane of readings. Wattage same as Test No. 5. For photometric curve see Fig. 12.

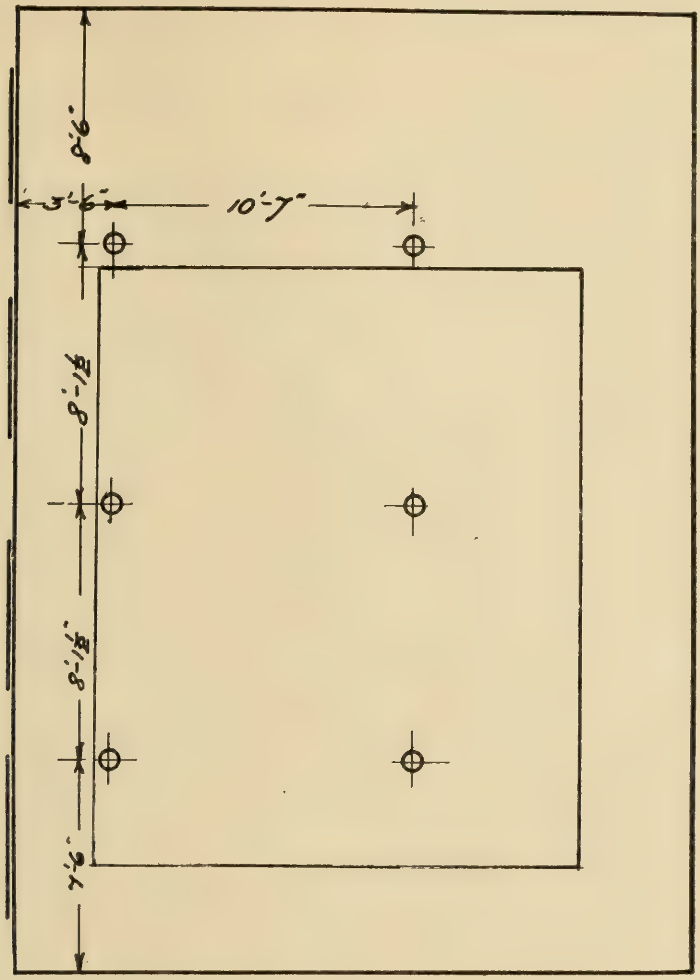


Fig. 13.—Arrangement of lighting units.

Station	Line voltage	Illumination foot-candles as read	Illumination foot-candles corrected for illuminometer calibration	Illumination foot candles corrected for rated voltage and average per station
1	122.1	1.94	2.93	2.39
	122.6	2.05	3.10	
2	122.6	2.38	3.60	2.98
	122.6	2.58	3.90	
3	122.8	2.52	3.80	3.12
	122.7	2.70	4.08	
4	122.7	2.61	3.94	3.11
	122.7	2.60	3.93	
5	123.2	1.90	2.87	2.24
	123.1	1.92	2.90	

Station	Line voltage	Illumination foot-candles as read	Illumination foot-candles corrected for illuminometer calibration	Illumination foot-candles corrected for rated voltage and average per station
6	123.2	2.27	3.43	2.58
	123.2	2.13	3.22	
7	123.4	2.35	3.55	2.80
	123.2	2.41	3.64	
8	122.7	2.40	3.62	2.84
	122.9	2.39	3.61	
9	123.3	1.86	2.81	2.18
	123.2	1.83	2.76	
10	123.3	2.08	3.14	2.43
	123.5	2.07	3.12	
11	120.2	2.11	3.19	2.69
	120.5	2.11	3.19	
12	120.5	2.25	3.40	2.87
	119.4	2.19	3.31	
29	119.8	2.11	3.19	2.72
	119.7	2.06	3.11	
30	119.8	1.97	2.98	2.68
	119.7	2.10	3.17	
31	119.8	1.76	2.66	2.32
	119.9	1.80	2.72	
32	119.9	1.47	2.22	1.99
	120.0	1.58	2.39	
33	120.1	1.37	2.07	1.78
	120.1	1.41	2.39	
34	120.2	1.62	2.45	2.08
	120.6	1.65	2.49	
35	120.5	1.81	2.73	2.25
	120.9	1.76	2.66	
36	121.0	1.79	2.70	2.27
	120.9	1.78	2.69	
45	121.0	1.25	1.89	1.57
	121.0	1.22	1.84	
46	120.9	1.17	1.77	1.45
	121.0	1.13	1.71	
47	121.0	1.11	1.68	1.42
	121.0	1.16	1.75	
48	121.1	1.07	1.61	1.31
	121.0	1.02	1.54	

Not corrected for voltage:

Mean foot-candles (back half of room 2.86

Maximum variation from mean (back half of room) ....—1.29 foot-candles (Station 48)

Maximum variation from mean (back half of room) 45.1%

Mean foot-candles (whole room, from ratio of Test No. 5) 3.02

Maximum variation from mean (assuming that this occurs in back half of room) ....—1.48 foot-candles

Maximum variation from mean 49.0%

Corrected for voltage:

Mean foot-candles (back half of room) 2.33

Maximum variation from mean (back half of room) ....—1.02 foot-candles (Station 48)

Maximum variation from mean (back half of room) 43.7%

Mean foot-candles (whole room, from ratio of Test No. 5) 2.44

Maximum variation from mean (assuming that this occurs in back half of room) ....—1.13 foot-candles

Maximum variation from mean 46.3%

TEST NO. 7.

For arrangement of outlets see Fig. 13.

Six-lamp scheme, lamps arranged in same manner as in Test

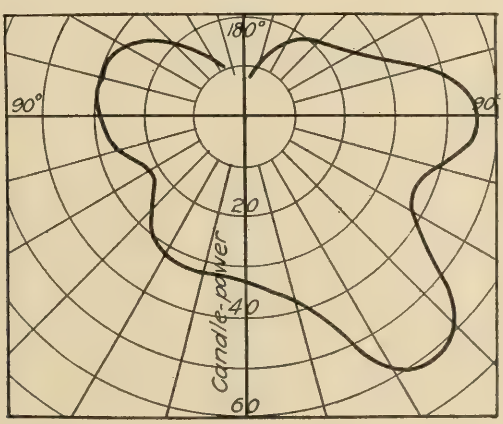


Fig. 14.—Photometric curve of 125-watt bowl-frosted graphitized-filament lamp with clear prismatic reflector; readings made in vertical plane.

No. 6. Each unit consisted of one 118-volt, 125-watt, 50 c-p., bowl-frosted graphitized-filament lamp and clear prismatic reflector. For photometric curve see Fig. 14.

Bottom of lamp came to a point 9′ 7½″ above the floor, or 7′ 0″ above the plane of readings. Wattage same as Test No. 4.

Station	Line voltage	Illumination foot-candles as read	Illumination foot candles corrected for illuminometer calibration	Illumination foot-candles corrected for rated voltage and average per station
1	121.2	1.43	2.16	1.92
2	121.1	1.73	2.61	2.33
3	121.2	1.91	2.88	2.55
4	121.2	1.92	2.90	2.57
5	120.6	1.54	2.32	2.13
6	120.4	1.87	2.82	2.58
7	120.3	1.99	3.00	2.76
8	120.4	1.98	2.99	2.75
9	121.2	1.53	2.31	2.04
10	121.5	1.77	2.68	2.34
11	121.3	1.95	2.94	2.61
12	121.3	1.86	2.81	2.49
13	121.2	1.89	2.86	2.52
14	121.1	1.88	2.84	2.54
15	121.0	1.89	2.86	2.55
16	121.1	1.73	2.61	2.32
17	120.2	1.99	3.00	2.76
18	120.9	1.99	3.00	2.69
19	121.0	1.97	2.98	2.66
20	120.9	1.89	2.86	2.57
21	121.2	1.98	2.99	2.64
22	121.5	1.92	2.90	2.54
23	121.3	1.83	2.76	2.45
24	121.6	1.80	2.72	2.39
25	121.2	1.75	2.64	2.57
26	121.2	1.94	2.93	2.60
27	120.8	1.95	2.94	2.66
28	120.7	1.98	2.99	2.72
29	120.7	1.94	2.93	2.66
30	120.7	1.85	2.80	2.54
31	120.1	1.69	2.55	2.36

Station	Line voltage	Illumination foot-candles as read	Illumination foot-candles corrected for illuminometer calibration	Illumination foot-candles corrected for rated voltage and average per station
32	120.6	1.46	2.20	2.01
33	120.7	1.43	2.16	1.98
	120.5	1.44	2.18	
34	120.2	1.71	2.58	2.37
35	120.7	1.81	2.73	2.48
36	120.2	1.80	2.72	2.49
37	120.5	1.85	2.80	2.55
38	120.5	1.79	2.70	2.46
39	120.1	1.83	2.76	2.55
40	121.7	1.72	2.60	2.28
41	121.5	1.37	2.07	1.74
42	121.5	1.44	2.18	1.81
43	121.8	1.47	2.22	1.93
44	121.9	1.52	2.30	1.72
45	122.0	1.43	2.16	1.87
46	121.5	1.46	2.20	1.93
47	121.5	1.34	2.02	1.78
48	121.5	1.16	1.75	1.56
	121.1	1.17	1.77	

Not corrected for voltage:

Mean foot-candles 2.64
Maximum variation from mean ....— .88 foot-candles (Station 48)
Maximum variation from mean 33.3%

Corrected for voltage:

Mean foot-candles 2.36
Maximum variation from mean ....— .80 foot-candles (Station 48)
Maximum variation from mean 33.9%

TEST NO. 8.

For arrangement of light sources, see Fig. 1.

Five-lamp scheme, lamps arranged symmetrically. Each unit consisted of one 117-volt, 187-watt, 75-c.-p., bowl-frosted graphitized-filament lamp and prismatic bowl reflector with light interior enamel. Bottom of lamp came to a point 9′ 7½″ above the floor, or 7′ 0″ above the plane of readings. For photometric curve see Fig. 3.

Station	Line voltage	Illumination foot-candles as read	Illumination foot-candles corrected for illuminometer calibration	Illumination foot-candles corrected for rated voltage and average per station
1	118.3	1.87	2.82	2.67
2	118.3	2.11	3.18	3.02
3	118.1	1.95	2.94	2.82
4	118.5	1.71	2.58	2.43
5	119.1	2.33	3.52	3.25
6	119.0	2.72	4.11	3.80
7	119.2	2.44	3.68	3.38
8	119.1	2.20	3.32	3.06
9	119.1	2.20	3.32	3.06
10	119.1	2.52	3.80	3.50
11	119.4	2.54	3.84	3.50
12	119.2	2.72	4.11	3.78
13	118.6	1.63	2.46	2.31
14	117.9	1.69	2.55	2.46
15	118.2	1.88	2.84	2.72
16	118.5	2.20	3.32	3.12
17	118.8	2.06	3.11	2.90
18	119.0	2.18	3.29	3.05
19	118.5	2.38	3.60	3.38
20	118.7	2.63	3.97	3.60
21	119.2	2.70	4.08	3.74
22	119.2	2.63	3.97	3.66
23	119.3	2.48	3.74	3.43
24	119.2	2.47	3.73	3.43

Not corrected for voltage:

Mean foot-candles 3.41
Maximum variation from mean ....— .95 foot-candles (Station 13)
Maximum variation from mean 27.8%

Corrected for voltage:

Mean foot-candles 3.17
Maximum variation from mean ....— .86 foot-candles (Station 13)
Maximum variation from mean 27.1%

COMPARISON OF EIGHT SCHEMES.

Some time after the completion of these tests, scheme No. 5 was installed in a few of the class rooms. From this system a mean foot-candle intensity of illumination of 2.61 was obtained. which intensity, however, apparently was not sufficient to meet all requirements, resulting in the following change: 100 watt bowl-frosted tungsten lamps were used, instead of 60 watt lamps

and more suitable satin-finished prismatic reflectors were selected. The authors had intended making an illuminometer test of this re-arrangement, but owing to the lack of time, were unable to carry out their desire. In order to arrive at the mean foot-candle intensity of illumination obtained by this system, for all practical purposes, we can deduce such figures from the ratio of the sizes of the lamps, namely, 60 to 100. By this method we arrived at a figure of 3.65 foot-candles. It is to be hoped that detailed figures based on actual tests of this installation, may be forthcoming in the near future.

This system is now standardized for the public schools in Newark, New Jersey. When it was first installed, there was more or less objection to it, on the part of the instructors. The chief objection being, that inasmuch as the light sources were so much further removed from the plane of illumination than were the four-lamp chandeliers, they did not produce the same amount of illumination, and as the light sources were, to a measure, surrounded by diffusing and reflecting mediums, thus reducing their intrinsic brilliancies and thereby removing their intense glare, that they were not so effective as the four-lamp system hung low with bare lamps, directly within the field of vision. However, as the instructors became acquainted with the value of the system, they were inclined to view the change in a different manner, until now every instructor and pupil working under this system has nothing but unqualified praise for it. The Board of Education are thoroughly satisfied with the illumination results produced, and likewise the economy of operation effected. With the scheme previously used, each room cost twelve cents per hour to operate, while with the present system, the cost is six cents with a material increase in effective illumination, and last, but by no means least, protection to the eye.

The illuminometer readings were made by T. W. Rolph, voltmeter and ammeter readings by H. S. Whiting and H. W. Shalling, ammeter readings for wattage by T. W. Rolph and all readings were registered by E. B. Rowe.

THE LIGHTING OF A BOWLING ALLEY.[1]

BY THOMAS W. ROLPH.

The science of illuminating engineering is so new that there are still many important problems which have received scant consideration. Bowling alley lighting is one of these. Up to the present time, little seems to have been written on the subject, although it contains engineering features of considerable interest. Furthermore, the sport of bowling is becoming more and more popular and the present lighting of alleys is, in most cases, poor, to say the least. This paper comprises a description of a successful bowling alley installation, results of illumination tests on the installation and a consideration of the important points brought out thereby.

The standard bowling alley is 63 feet in length from the foul line to the pit. The runway extends 15 feet back from the foul line. The pins occupy a space of 3 feet at the end of the alley. The width of an alley is 3 ft. 6 in. or 5 feet including the 9 in. gutter on each side. The entire length of the alley should be lighted well enough for a ball to be seen plainly at any point. The pins should receive additional illumination sufficient to make them stand out clearly against the dark background of the pit. The lighting must be accomplished by means of lamps entirely hidden from the eyes of a bowler standing at any point on the runway. It is desirable also to protect the eyes of the bowler from the regular reflection of the light-sources on the surface of the alley, which is polished. This regular reflection is a common fault in bowling alley lighting, appearing as a series of bright spots on the surface. It would seem that the best method of fulfilling the illumination requirements is by the use of a row of light-sources over the alley, each light-source directing the maximum quantity of light in the direction of the pins, and allowing no light to reach the bowler's eyes either directly or regularly reflected from the surface of the alley. The lighting of the pins must be treated as a separate problem

[1] A paper read before the New York Section of the Illuminating Engineering Society on Jan. 20, 1910.

of local illumination superimposed upon the general illumination. The lighting of the runway should be treated as a separate problem and good general illumination provided.

The installation here described is made along these general lines. This installation is "The Brunswick" located in Newark, Ohio. It comprises 5 alleys, used for ten pins, duck pins and quintette. Each alley is lighted by one row of 8 lamps, each consisting of a 40-watt clear tungsten lamp, equipped with a steel

Fig. 1.—Illuminated bowling alley.

reflector giving the distribution shown in Fig. 4. The light-units are placed 9 feet apart and 9 feet from the floor to the center of the lamp. The first light is placed directly over the foul line, thus bringing the seventh light 54 feet from the foul line or 9 feet from the pit. The eighth light is used to produce the higher illumination at the pins. This light-unit itself is the same as the other seven, but it is placed 5 feet from the end of the alley and 5 ft. 6 in. above the floor. The run-ways for the five alleys are lighted by two 100-watt lamps with

"intensive" prismatic reflectors. Fig. 1 shows a night photograph of the installation. The two lamps shown on the ceiling over the alleys are for the purpose of providing a low general illumination when the alleys are being cleaned or at other times when they are not in use. Fig. 2 shows a plan and elevation giving the location of lamps.

The type of steel reflector used is illustrated in Fig. 4 which also gives the photometric curve of the light-unit. The reflector is of the 30° angle type and is 6½ in. in diameter. The maximum candle-power with a 40-watt lamp is 74 and is at an angle of about 45° from the vertical.

The illumination readings were made with a standard

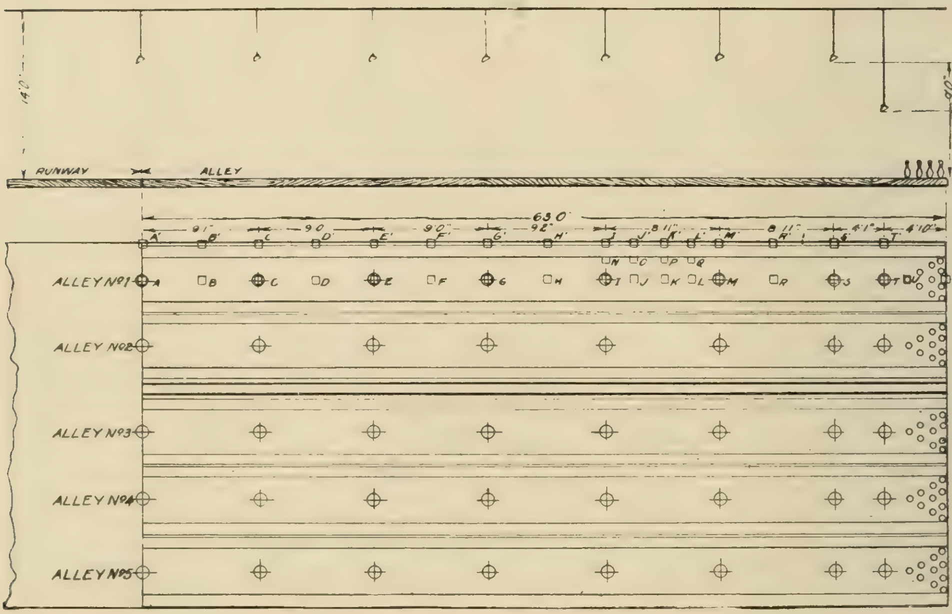


Fig. 2.—Plan and elevation of the lighting equipment.

illuminometer. The voltage was read simultaneously with each illumination reading and the illumination readings corrected to the rated voltage of the lamps, by means of the characteristic curve of the tungsten filament. The rated voltage of the lamps was 113 and the voltage varied from 108.7 to 115.5.

The readings were taken with the photometer placed on the floor. During the horizontal readings, the light-units were raised above 9 feet, a distance equal to the height of the test plate of the instrument above the floor. During the vertical readings, the lamps were at the correct height above the floor.

The following tests were made, all with the light-units over alley No. 1 only, lighted:

Test No. 1—Alley No. 1.

Test No. 2—Alley No. 2.

Test No. 3—Alley No. 3.

Test No. 4—Alley No. 4.

Test No. 5—Alley No. 5.

Test No. 6—Along a line 2 ft. 7 in. from the center line of alley No. 1.

Test No. 7—Alley No. 1 with 4 light-units 9 ft. apart and 9 feet high, each light-unit consisting of a 40-watt clear tungsten lamp and steel reflector.

Test No. 1 shows the illumination on a single alley. The illumination is shown graphically in Fig. 5, which also shows the calculated illumination. The maximum deviation from the mean along the alley is 17.1 per cent., while the greatest deviation of adjacent high and low points from their mean is 14.2 per cent.

The latter figure would seem to be the most important, in a test of this nature, since a gradually increasing illumination thus giving a high maximum deviation from the mean would not necessarily be objectionable, while with the same or lower maximum deviation from the mean, it would be decidedly objectionable to have a comparatively high deviation of adjacent high and low points from their mean. This point will be taken up further under the consideration of test No. 7. The difference between the calculated illumination and the measured illumination, is a matter of some interest. The percentage difference is higher at the high points (half-way between light-units) along the alley than at the low points (directly under light-units). The most probable reason for this is that commercial variations in the lamp, reflector and socket cause the distribution of light to be different from that obtained in the laboratory. Another possible explanation is a variation of the test plate in the photometer from the cosine law.

Supplementing the test figures, it may be stated that the alley

TABLE I.—TESTS 1, 2, 3, 4 AND 5.

HORIZONTAL ILLUMINATION.

Test station.	Intensity in foot-candles. Test No. 1 (alley No. 1)	Test No. 2 (alley No. 2)	Test No. 3 (alley No. 3)	Test No. 4 (alley No. 4)	Test No. 5 (alley No. 5)	Summation of intensities. Tests Nos. 1 and 2	Tests Nos. 1, 2, 3 and 4	Tests Nos. 1, 2 (twice) and 3 (twice)
A	.466	.320	.124	.0489	....	.786	.959	1.35
B	.881	.517	.157	.0783	....	1.40	1.63	2.23
C	.821	.578	.209	.105	....	1.40	1.71	2.40
D	1.04	.679	.221	.111	....	1.72	2.05	2.84
E	.959	.672	.228	.128	....	1.63	1.99	2.76
F	1.23	.755	.255	.142	....	1.99	2.38	3.25
G	.924	.740	.271	.152	....	1.66	2.09	2.95
H	1.20	.783	.292	.170	....	1.98	2.49	3.35
I	1.01	.716	.302	.178	....	1.73	2.21	3.05
J	1.12	.762	.297	.167	....	1.88	2.35	3.24
K	1.10	.739	.300	.182	....	1.84	2.32	3.18
L	.989	.698	.309	.192	....	1.69	2.19	3.00
M	.874	.714	.291	.187	.0878	1.59	2.07	2.88
N	.991	...	...	...	....	...	...	...
O	1.06	...	...	.	....	...	...	...
P	1.03	...	...	...	....	...	...	..
Q	.960	...	...	...	....	...	...	...
R	1.11	.727	.292	.168	....	1.84	2.30	3.16
S	1.26	.797	.276	.172	....	2.06	2.51	3.41
T	2.10	1.05	.274	.169	....	3.15	3.59	4.75
U	2.97	.966	.274	.152	....	3.04	4.36	5.45
V	2.01	.801	.162	.0807	....	2.81	3.05	3.93
[1] Mean ft.-candles along alley	1.05	.737	.279	.163	....	1.78	2.23	3.06

[1] Stations, E, F, G, H, I, J, K, M and R only, considered. These give a fair indication of the mean, neglecting local illumination at the pins and low points near the runway. These low points will be brought up by the lamps over the runway.

TABLE I. —(*Continued.*)

Test Station	Test No. 1 (alley No. 1)	Test No. 2 (alley No. 2)	Test No. 3 (alley No. 3)	Test No. 4 (alley No. 4)	Test No. 5 (alley No. 5)	Tests Nos. 1 and 2	Tests Nos. 1, 2, 3 and 4	Tests Nos. 1, 2 (twice) and 3 (twice
Max. dev. from mean along alley...	.18 ft.-c.	.065 ft.-c.	.051 ft.-c.	.035 ft.-c.	....	.19 ft.-c.	.26 ft. c.	.29 ft.-c.
	17.1%	8.8%	18.3%	21.5%	....	10.7%	11.6%	9.5%
Station of max. dev. along alley....	F	E	E	E	....	M	H	H
Max. dev. of adjacent high and low points from their mean........	.153 ft.-c.	.0415 ft.-c.	.0135 ft.-c.	.0095 ft.-c.	....	.18 ft.-c.	.20 ft.-c.	.245 ft.-c.
	14.2%	5.8%	5.6%	5.3%	....	9.9%	8.8%	8.2%
Mean of the two stations	1.08 ft.-c.	.714 ft.-c.	.242 ft.-c.	.178 ft.-c.	....	1.81 ft.-c.	2.29 ft.-c.	3.01 ft.-c.
Stations..........	F, G	E, F	E, F	M, R	....	E, F	G, H	E, F

VERTICAL ILLUMINATION ON PINS.

Pin No.	Intensity in foot-candles					Summation of intensities		
1	2.25	1.19	.524	.299	....	3.44	4.26	5.68
3	2.68	1.16	...	...	....	3.84	...	...
5	2.83	1.26	...	...	....	4.09	...	...
6	2.73	1.15	...	...	....	3.88	...	...
9	2.73	1.21	...	...	...	3.94	...	...
10	2.49	1.08	.470	...	....	3.57	...	5.59
Mean ft.-c.	2.62	1.18	.497	...	....	3.79	...	...
Max. dev. from mean	.37 ft.-c.	.10 ft.-c.	...	...	....	.35 ft.-c.	...	...
	14.1%	8.5%	...	...	....	9.3%	...	...
Station	1	10	...	...	....	1	...	...

appeared exceptionally well lighted. The illumination along the alley appeared low, but sufficient for illuminating a ball so that its movements could be distinctly seen. The points of high and low intensity shown by the illumination curve, were easily discernible but not objectionable. The pins stood out plainly against the back-ground of the pit. The lamps were entirely hidden from the eyes of a bowler. Regular reflection on the alley was obtained from the second lamp only and the candle-power in the direction of the light-rays reflected to the eye is so low, as shown by the photometric curve, that the glare on the surface of the alley was hardly noticeable. No regular reflection is received from the first light-unit, over the foul line, since the surface of the runway is not polished.

Tests Nos. 2, 3, 4 and 5 were made for the purpose of de-

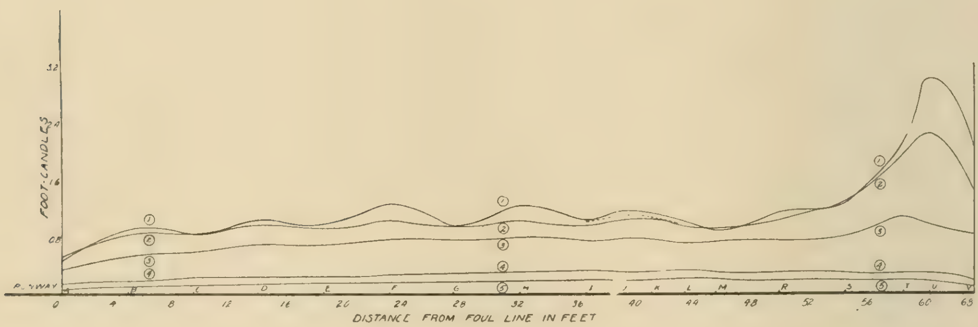


Fig. 3.—Illumination along the alley.

termining how much the illumination on an alley is increased by the lamps over the other alleys. Fig. 5 shows graphically the results on the five alleys when alley No. 1 alone is lighted. The increase is greater than one would estimate by observation. When the five alleys are all lighted, the illumination does not appear to be markedly better than when one alley alone is lighted, except that in the former case it appears more uniform. When all the alleys are lighted, the illumination on each alley appears uniform to the eye.

The illumination on one of two alleys, when each are lighted by a row of lamps is found by adding the values of tests Nos. 1 and 2. The illumination on the center alley of the five, when

all are lighted, is the sum of the values of test No. 1, twice the values of test No. 2 and twice the values of No. 3. The illumination on alley No. 1 when all 5 are lighted is the sum of the values obtained in tests Nos. 1, 2, 3, 4 and 5. The value obtained in test No. 5 is so small, however, that it can be neglected.

The fact that an alley lighted with 3 foot-candles (alley No. 3 when all are lighted) appeared only slightly better than one lighted with 1 foot-candle is evidence of the leniency with which the eye judges illumination. One may conclude from the results of these tests and observation of the alley that it is desirable to have an intensity of 1½ to 2 foot-candles (horizontal illumination) along an alley and 4 to 5 foot-candles vertical illumination on the pins. The latter will cause a horizontal illumination of

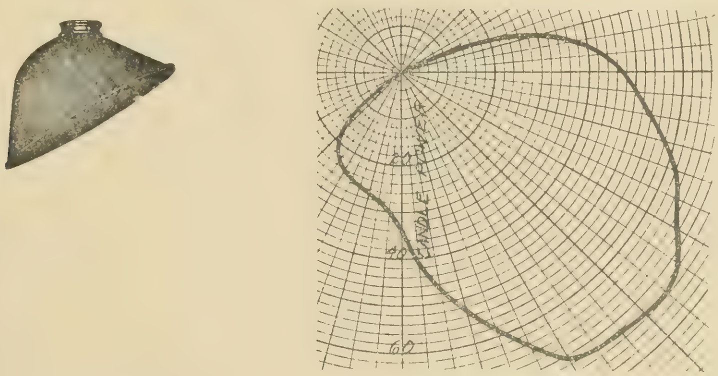


Fig. 4.—Steel reflector and candle-power distribution.

about the same intensity on the space occupied by the pins.

Test No. 6 was made to determine the illumination when a row of lamps is placed between two alleys. The readings were made along a line 2 ft. 7 in. from the center line of alley No. 1, with the lamps over alley No. 1 only, lighted. The illumination obtained is shown graphically in Fig. 6. This curve holds for a height of 9 feet, but by comparing it with curves 1 and 3 of Fig. 5, it will be seen that for all ordinary heights, this is a very good method of lighting a number of alleys. Each alley, however, should have a light-unit for illuminating the pins.

Test No. 7 was made for the purpose of determining the lowest possible observable variation in illumination on an alley. With the lamps 9 ft. apart, a reflector was selected and the height so adjusted that the difference in illumination between two points

TABLE II.—TEST NO. 6.

Readings on a line 2 ft. 7 in. from center line of alley No. 1.
Light-units over alley No. 1 only, lighted.

Station	Horizontal foot-candle
A	.471
B	.824
C	.757
D	.953
E	.982
F	1.15
G	.929
H	1.10
I	.980
J	1.07
K	1.03
L	.973
M	.881
R	1.05
S	1.23
T	1.93
[1]Mean ft.-c. along alley	1.01
Max. deviation from mean along alley	.14 ft.-c.
	13.9%
Station of max. deviation	F
Max. deviation of adjacent high and low points from their mean	.086 ft.-c.
	8.5%
Mean of the two stations	1.01
Stations	G, H

TABLE III.—TEST NO. 7, FOR OBSERVABLE VARIATION IN ILLUMINATION.

Two stations selected by the eye as points of maximum and minimum intensity; approximately 4½ feet apart.

Station	Foot-candles
Maximum point	1.16
Minimum point	1.10
Mean	1.13
Deviation from mean	.03 ft.-c.
	2.7%

approximately 4½ feet apart was barely discernible. The illumination at these two points was then measured. The deviation of each point from the mean of the two was 2.7 per cent.

To one accustomed to working on other classes of lighting in-

[1] Stations E, F, G, H, I, J, K, M and R only, considered. These give a fair indication of the mean, neglecting local illumination at the pins and low points near the runway. These low points will be brought up by the lamps over the runway.

stallations, this is a surprising fact. In stores, offices, assembly halls, etc., a deviation of 30 to 40 per cent. from the mean is considered uniform for all practical purposes. In that class of work the eye cannot detect deviations of less than approximately 25 per cent. Distinction should be made, however, between maximum deviation which the eye can detect, and maximum deviation which is not objectionable. In store-lighting, for example, it is not uncommon to find, in stores which the public would call exceptionally well lighted, a deviation from the mean of 100 per cent. and more, the deviation being unnoticed by the public. So also in the lighting of a bowling alley, while 2.7 per cent. deviation from the mean is discernible, test No. 1, in which the variation was not objectionable, showed a deviation of 17

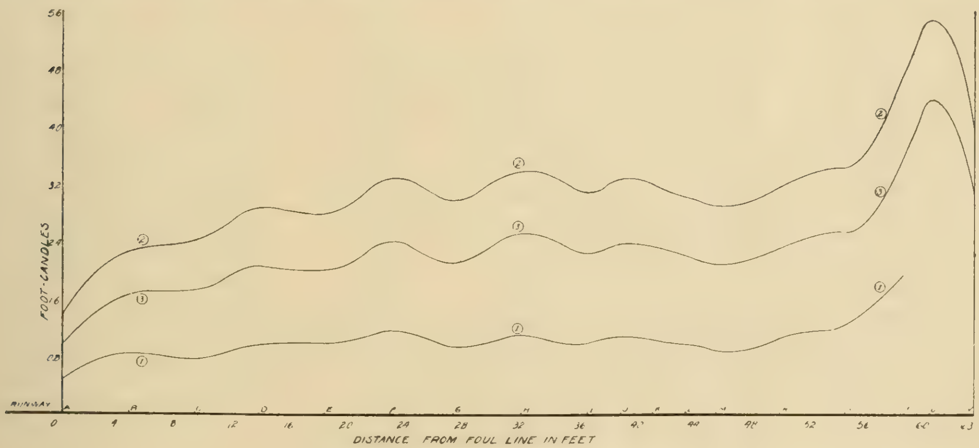


Fig. 5.—Illumination along the alley.

per cent. along the alley and a deviation of 14 per cent. of two adjacent high and low points from their mean. It is worth recording that the deviation of 2.7 per cent. which could barely be detected on the alley when viewed from the runway, could not be detected at all when looking across the alley from one side. This would indicate that the eye is most sensitive to differences in illumination when the surface illuminated is viewed at a considerable angle, possibly due to a fore-shortening effect which would cause the points of high and low intensity to appear closer together, thus enabling the observer to compare them more easily.

With a lighting system such as the one described, it is inevitable that the wall back of the pit will be highly illuminated. Hence, the wall should be finished in a dark color, if possible.

Furthermore, since the surface of the alley is polished and is therefore a good reflector, any objects on the wall will appear reflected on the surface of the alley. In one case, where this type of lighting system was installed, there was complaint of a dark shadow on the alley. Upon investigation, it appeared that the wall back of the pit was dark in color part way to the ceiling and light above that. The reflection of the wall on the alley showed apparently a considerable change in the illumination where the line dividing the light and dark parts of the wall was dimly reflected. In another case there were large windows back

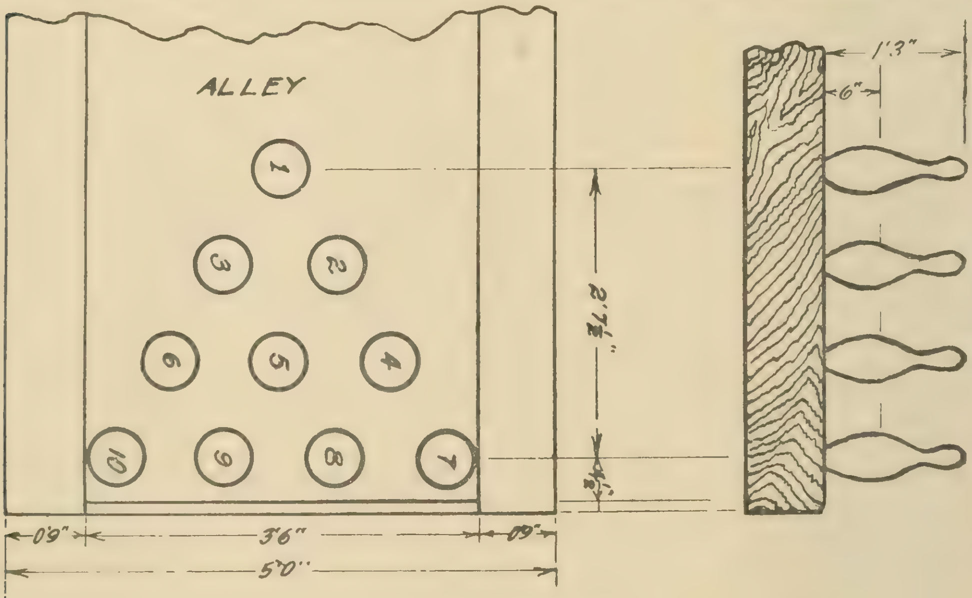


Fig. 6.—Location of pins.

of the pit and the images of the lamps could be seen on the alley, reflected first from the windows.

In many cases bowling alleys are located in basements where the ceiling height will not allow the lamps to be placed as high as 9 feet above the floor. It is then necessary to place them closer together, or to use a reflector giving a different photometric curve. Placing the lamps closer together and lower, raises the intensity, but this disadvantage, if it is one, can be overcome by using one row of lamps to illuminate two alleys. It is the experience of the writer that satisfactorily uniform illumination is difficult, if not impossible, to obtain with the ordinary types of angle reflectors, if the lamps are placed farther apart than their height above the floor.

ERRATA.

The following errors appear in the paper on "Color Measurements of Illuminants" in the April, 1910 issue of the *Transactions*, attributable to the fact that no proof was submitted to the author:

Page 190, line 7, end, should be Koettgen.

Page 192, line 13, between "several" and "acetylene" insert "acetylene burners of different types, and gives an."

Page 195, line 1, insert "on" between "those" and "sunlight."

Page 198, sixth line from bottom, should read "The colorimeter results as obtained are not" etc.

Page 200, eleventh line from bottom, should be "their sum is 100."

Page 201, third line from bottom, fifth word from end, should be "plotted."

Page 202, sixth line from bottom, insert "at" between "that" and "the."

Page 203, tenth line from bottom, insert "and" between "sky" and "for." Fourth line from bottom, equation should read:

$$E = \frac{\lambda^{-5}}{e^{\left(\frac{14{,}400}{\lambda T}\right)} - 1}.$$

Page 204, third line, Colorimeter values in the table not being italicised as indicated, this sentence should read "the colorimeter values are the second ones given."

Page 207, A note at bottom of page should call attention to the fact that the table of color values is on the following page.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. V. NOVEMBER, 1910. NO. 8

MINUTES OF COUNCIL MEETING.

NOVEMBER 11, 1910.

A meeting of the council was held on November 10 in the general office. The minutes of the previous meeting were amended and approved.

Secretary P. S. Millar presented a report of the financial and the membership status of the Society. In it he stated that the gross receipts to November 1st had been $12,659.45, while the disbursements had aggregated $8,264.71; and that the membership of the Society, exclusive of fifty-four applications under consideration, totaled 1,555.

For the committee on constitutional revision Mr. Millar also submitted an amendment to the constitution as given below:

"The terms of the members of all standing and temporary committees shall terminate on the second Thursday of February of each year, when the president shall constitute the membership of all standing committees and of such temporary committees as may have further duties to perform."

Attention was directed to the fact that under the present provision of the constitution, the terms of all committees terminate on the second Friday of January of each year, thereby leaving the Society without any committees for approximately one month before other committees are appointed by the newly-elected president. To obviate this the amendment had been proposed. It was duly signed by more than one hundred members and accordingly accepted by the meeting. It will be submitted to the vote of the members at the election next month.

Fifty-four applicants were elected members. A resolution appropriating $25.00 for indexing Volume V of the Transactions, and the approval of payment of bills aggregating $1,973.90 were among the other business transacted.

SECTION MEETINGS.

NEW YORK SECTION.

At a meeting of the New York Section held on November 11, Mr. A. J. Marshall, as secretary of the Section, outlined the papers read and discussed at the recent Baltimore convention of the society and the lectures on illuminating engineering delivered at Johns Hopkins University. The convention and the lecture course were then discussed by Messrs. A. H. Elliott, H. T. Owens, E. N. Hyde, A. S. McAllister and O. Hyatt. Prof. G. S. Macomber described the course in illuminating engineering being given at Cornell University, in which use will be made of the information acquired during the Johns Hopkins lecture course in so far as it can be applied to the conditions at Cornell.

The secretary announced that the paper by Mr. Bassett Jones, Jr., entitled "A Study of Reflecting and Diffusing Media" which was prepared for the December meeting, will be held over for the February meeting. On December 8, there will be two papers. A paper by Prof. E. L. Nichols, of Cornell University, will deal with the early history of photometric standards. Mr. Bassett Jones, Jr., will present a paper entitled "The Lighting of the Allegheny Soldiers' Memorial Building in Pittsburg." This paper will be illustrated by means of colored lantern views. Printed copies of the paper will be distributed a week or more prior to the meeting. This paper will deal with what is probably the most elaborately lighted building ever constructed, where practically all characteristics of electric illuminants have been used in unique ways.

At the January meeting three papers will be presented. Dr. P. W. Cobb will read a paper on the physiological effects of light on the eye. Dr. Nelson M. Black will treat of the effects of ultra-violet light on the eye. Mr. Paul F. Bauder will outline the results of experimental investigation of the effect of reflected light in differently treated interiors.

In addition to the presentation of the paper by Mr. Jones at the February meeting there will be a discussion of the subject "Light and Architecture" led by Mr. Henry Hoanbostel of the firm of architects responsible for the design of the Allegheny County

Soldiers' Memorial Building. It is expected that this meeting will be well attended by architects, decorators, designers and fixture house representatives as well as by members of the Society.

NEW ENGLAND SECTION.

The New England Section held its regular monthly meeting at the Edison Building in Boston on November 14. The meeting was devoted principally to a discussion of schoolroom lighting, the opening remarks being made by Mr. B. B. Hatch. Dr. Louis Bell, Dr. C. H. Williams and Mr. C. H. Smith also contributed to the discussion.

At a meeting of the Section to be held on Dec. 12th, Mr. C. A. B. Halvorson, will present a paper on arc lamps, the scope of which will embrace many features especially interesting to central station operators and others whose commercial problems involve illumination with large units.

Chairman C. O. Baker announced that plans are on foot to establish a "Question Box" with the object of furnishing members promptly with answers to troublesome problems occurring in their practice. During February the Section will hold an afternoon session at which three papers will be presented.

CHICAGO SECTION.

A meeting of the Chicago Section was held on Thursday, November 17th, in the Chicago room at the Great Northern Hotel. The meeting was held in connection with the noon luncheon. A résumé of the convention at Baltimore was given by Dr. M. G. Lloyd. The lectures on illuminating engineering were reviewed and discussed by Messrs. Geo. C. Keech, F. A. Vaughn, Geo. H. Jones, P. F. Williams, T. R. Beebe, Wm. Durgin, W. R. Lyon, C. C. Schiller, F. J. Pearson and Norman Macbeth.

At the December meeting of the section, papers will be presented by Prof. J. M. Bryant and Mr. H. G. Hake on the results of original research at the laboratory of the University of Illinois. At the January meeting a discussion on "Luminous Efficiency" will be led by Mr. A. L. Eustice. In February, the subject "Illuminating Problems in the Smaller Cities" will be discussed. At the March meeting, Mr. Charles A. Luther will read a paper entitled "Illuminating Features of the Peoples Gas and Coke Company's New Building in Chicago." Mr. C. R. Gillman will

present a paper on "Train and Car Lighting" at the April meeting. "The Lighting of Small Rooms" will be the subject of a paper by Mr. J. R. Cravath at the May meeting. "Natural Daylight Illumination" will form the subject of a paper to be presented at the June meeting.

PHILADELPHIA SECTION.

The Philadelphia Section held a meeting on Friday November 18th, which was attended by 98 members and guests. The programme consisted of a review of the Baltimore Convention papers, by members of the Section who had attended the Convention. Some twenty or more speakers had prepared brief sketches of the papers, but owing to limited time, only ten were given. Those presented were by Messrs. R. B. Ely, G. B. Regar, Chas. A. Holdcraft, J. G. Felton, W. H. Fulweiler, L. B. Eichengreen, B. J. Deck, F. L. Kellner, Geo. S. Barrows, and E. E. Robertson.

At the December meeting a paper will be presented by Mr. L. B. Eichengreen on "The Lighting of a Large Stable Building." Printed copies of this paper will be distributed a week or more prior to the meeting.

REPORTS OF THE COMMITTEE ON NOMENCLATURE AND STANDARDS AND THE SUB-COMMITTEE ON PHOTOMETRIC UNITS.[1]

To the Officers and Members of the Illuminating Engineering Society.

GENTLEMEN :—

The Sub-Committee on Photometric Units, of the Committee on Nomenclature and Standards, has submitted a report of progress which suggests certain definitions of photometric magnitudes and units. This report was not received in time to submit to the members of the Main Committee for action in advance of this meeting. The Sub-Committee's report is submitted herewith without action on the part of the Main Committee, but I beg leave to suggest that the suggestion made should receive during the time intervening between this and the next annual meeting the careful consideration of the members. During this time the suggestions will also be considered by the members of the Main Committee.

The suggestions covered questions of vital importance to our profession.

Yours respectfully,

(Signed) ALEX C. HUMPHREYS.

Chairman of Committee on Nomenclature and Standards.

Dr. A. C. Humphreys,

Chairman Committee on Nomenclature and Standards.

DEAR SIR :—

The Sub-Committee on Photometric Units begs to report that the work of the Committee has been continued during the past year along the lines indicated in the report of September 22, 1909. As a result of the year's work, the Committee would submit as a Progress Report, the following definitions of photometric magnitudes and units. This set of definitions is incomplete and is probably open to objections. The Sub-Committee hopes that the material of this Progress Report may be subjected during the coming year to a great deal of critical scrutiny

[1] Submitted at the Baltimore Convention of the Illuminating Engineering Society on October 24, 1910.

by members of the Society and others interested in this subject, so that the Committee benefiting thereby may be better able to frame a final report next year.

Respectfully submitted,
A. BLONDEL,
A. E. KENNELLY,
E. L. NICHOLS,
EDWARD B. ROSA,
C. H. SHARP, Chairman.
Sub-Committee on Photometric Units.

PROGRESS REPORT OF SUB-COMMITTEE ON PHOTOMETRIC MAGNITUDES AND UNITS, 1910.

Light (flux) is the stimulus produced by radiation which excites vision. It is proportional to the rate of flow of radiant energy and to a stimulus coefficient which depends chiefly on the spectral distribution of that energy.

The presence of a flux of light is recognized by the *illumination* which it produces. The illumination is proportional to the flux per unit area of the illuminated surface or to the flux density incident on that surface.

The *luminous intensity* of a point source of light is measured by the luminous flux per unit solid angle in the direction in which the intensity is taken. Two point sources of light are said to be equal in intensity when they produce equal illuminations at equal distances. Due to the fact that standardized point sources of light of unvarying intensity are obtainable, while it is not practicable to obtain a standardized luminous flux or a standardized illumination without a standardized source of light, the unit of luminous intensity has become the fundamental photometric unit from which the values of the unit of flux, of illumination, etc. are derived; that is, the unit of intensity is the fundamental photometric unit, although flux is the fundamental photometric magnitude.

The unit of luminous intensity is the *candle*. By candle is meant the common candle of Great Britain, France and America, for which the name "International Candle" has been proposed.

The term "candle-power" is used as the equivalent of the term "luminous intensity in candles."

The unit of luminous flux is the flux of light produced in a unit solid angle (one steradian) by a uniform source of one candle placed at the apex of the angle. This unit is called the *lumen*.

The unit of illumination is the illumination which is produced by a flux of one lumen falling on a unit plane area. This is equivalent to the illumination produced by a source of one candle at unit distance.

The unit of illumination in the c. g. s. system is the lumen per square centimeter. As a practical unit the millilumen per square centimeter is recommended.

In English speaking countries the unit of illumination commonly employed is the "foot-candle" (lumen per square foot). This designation is preferable to "candle-foot." The corresponding metric unit "meter-candle" (lumen per square meter) is called the *lux* (plural lux). It is desirable that all values of illumination should be expressed in terms of lumens per unit area, the unit of area being chosen in accordance with the requirements of the situation.

By the *specific intensity* of a luminous surface or body is meant its apparent luminous intensity per unit area, expressed in candles per square centimeter of apparent area, or area projected on a plane perpendicular to the direction in which the measurement is made and including only a surface of small dimensions in comparison with the distance at which the measurement is made.

By the *specific radiation* of a luminous surface or body is meant its total luminous flux per unit area expressed in lumens per square centimeter or millilumens per square centimeter.

By *mean spherical intensity* of a source of light is meant the average value of its intensity as taken in all directions in space. It is equal to its total luminous flux in lumens divided by 4π.

By *spherical reduction factor* of a source of light is meant the ratio of its mean spherical intensity to its mean horizontal intensity.

The names of these units in the c. g. s. system and their mathematical relations to each other are shown in the accompanying table:

Photometric magnitudes		Name of unit	Equation of definition.
1. Intensity of light or strength of luminous source.		(International) candle	$I = \frac{dF}{d\omega}$; $I_s = fI$
2. Luminous flux.		Lumen	$F = 4\pi I_s$; $F = I\omega$
3. Illumination	Specific flux or flux density.	$\frac{\text{Lumens}}{\text{cm}^2}$ of $\frac{\text{Millilumens}}{\text{cm}^2}$	$E = \frac{F_i}{S} = \frac{I}{r^2}$
4. Specific radiation	Specific flux or flux density. / Brightness.	$\frac{\text{Lumens}}{\text{cm}^2}$	$R = \frac{F_e}{S} = mE$
5. Specific intensity	Brightness.	$\frac{\text{Candles}}{\text{cm}^2}$	$f = \frac{I}{S^{[1]} \cos e}$
6. ——		Lumen-hours or lumen-seconds	$Q = FT$

International candle abbreviated to C.
International lumen abbreviated to L.
Hefner unit abbreviated to HK, as now used in Germany.
f is the spherical reduction factor of a light source.
ω is a solid angle $= \frac{\text{area on a sphere subtending the angle}}{\text{square of radius}}$.

r is distance from light source in centimeters.
m is coefficient of reflection or radiation, $(1-m =$ absorption$)$.
S is an area in square centimeters.
e is angle of emission.
i is an angle of incidence.

[1] S refers to surface seen from the point at which I is taken.

DISCUSSION.

Dr. Edward B. Rosa:—This report is offered as a progress report, and not a final report. I suggest that the Convention instruct the committee to present a final report one year from now, and in the meantime the committee be instructed to correspond with certain societies and individuals in Europe with regard to the matter of nomenclature. The committee has not made any approaches towards Germany or representatives of Germany. If it were possible, by making some slight changes in the nomenclature that is proposed, to get Germany to agree to the nomenclature, it would be of very great advantage. Some of the European countries that have taken considerable interest in the subject are a little bit sensitive about having things done without being consulted,—and I should favor holding the report in abeyance for another year. In the meantime, the members who have occasion to use the symbols as proposed cannot become so firmly fixed in their habits in one year's time but that a slight modification might be made. Some of the letters and names which are proposed are and have been in use in Germany and some are not in use, and some of the letters are different from those now in use. It seems to me it might be possible, although perhaps that is hoping for a good deal, to obtain nomenclature more widely international than this is likely to be without such action. I place the matter in the form of a motion to that effect.

President Hyde:—The motion for discussion and action is that the subcommittee on photometric units be instructed to present at the next annual convention a final report on nomenclature and units, and that in the meantime the committee endeavor to secure the cooperation, if possible, of foreign countries.

Dr. A. S. McAllister:—As the report now stands selection has been made of the symbol *E* and also of the symbol *I*. *E* is the well recognized symbol of electromotive force, and *I* that of current. It seems to me that unless there is some very important reason for using these symbols for photometric quantities they should not be selected.

Mr. P. S. Millar:—Dr. Rosa spoke of securing international concurrence in this report. He rather intimated that the concurrence of England and France, either official or unofficial, had

been secured or promised. It would be interesting to learn whether or not such is the case.

Dr. Sharp:—The subcommittee has not endeavored, as yet, to get any action by foreign bodies on this question. Very fortunately one very influential foreign member is on the subcommittee, namely, Professor Blondel, of Paris. Professor Blondel is the originator of the system of units as given here. His original suggestions have been slightly modified by some very valuable suggestions emanating from other members of the subcommittee, but fundamentally, the suggestions are Professor Blondel's, Professor Blondel carries a great deal of weight, particularly in France, so that is is hoped that we can influence the French scientists through him. As to England, I believe that it is the intention of the (British) Illuminating Engineering Society to appoint a subcommittee or committee somewhat similar to our own. I have taken occasion in corresponding with some of the officials of the Society to suggest that it would be a desirable thing for them to do. I trust that they will do so, and that we can cooperate with them, and get a common system of symbols in both countries in that way.

Mr. F. J. Pearson:—Does the system selected have for its basis the c. g. s. system? Are we to use the metric system in calculations, or the English equivalent of the metric system? In adopting any specific symbols and units, of illumination, the society should take the matter up with the various other societies such as the American Institute and the British Institution of Electrical Engineers, and select a system which will be uniform with the present system of purely electrical unit.

Mr. G. H. Stickney:—In the report no mention is made of the unit of specific consumption as is used in electrical literature, for instance, the watts per candle-power, or something of that sort. I think it would be well to define such a unit in the report.

Mr. E. L. Elliott:—In connection with the question concerning the use of I and E, I should like to ask if it would be practicable to use the letter J in place of I? I think this is the German practice at the present time, and it might help us in getting German cooperation to adopt the letter J.

Mr. R. C. Ware:—Dr. Rosa expressed the opinion that it would be a good idea to begin using some of the symbols conditionally to their being changed. It seems to me that possibly we had better steer clear of using any new ones until the report is finally adopted, because of the confusion that would arise from a mixture of two or three definitions and standards.

Mr. H. T. Owens:—I believe it is very important that copies of this report be in the hands of the members as soon as possible. I think that is one of the most important things to be done.

Dr. Sharp:—Regarding the conflict of new with old symbols, it was not believed that there was sufficient liability for any confusion to arise to discontinue the use of the letters mentioned. *E* and *I* have been used in illuminating work for quite a number of years now, and it is hard to see how anybody is going to confuse electromotive force and illumination or intensity of electric current with the intensity of a source of light. They are so radically different. There are not letters enough to take one for every different physical quantity that we have to use. For example, *f* is often used for "force," and in the report it is used for "flux;" there is no possibility of confusing those things. It may be that it would be a good thing to avoid the use of the letters *E* and *I*, because they are used for e. m. f. and current, but the committee has not considered that argument very seriously.

As to the use of the c. g. s. system or of the French metric units as against the English, it is to be noted that in the report the English units have been defined, and that the unit of illumination is the only important one that is distinctly English. The lumen is independent of the unit of length. The candle, being the fundamental unit is the same in all countries, so that this question concerns the units of illumination, specific radiation and specific intensity only. In the body of the report, the unit of illumination commonly used is referred to as the foot-candle, which is defined as the lumen per square foot, and the report further says that this designation is preferable to candle-foot. If we are to make a choice, we should prefer foot-candle to candle-foot, as the plural of foot-candle is foot-candles, while the plural of candle-foot is candle-feet, which is pretty

bad. Corresponding reference is made to the metre-candle, and the sanction of the name "lux" is given to the metre-candle. Now, the significance of that is that we understand by lux 1 metre-candle and not 1 Hefner-metre. The term lux was originally defined in Blondel's work as metre-candle, the candle in that case being the *bougie décimal,* or the one-twentieth part of the platinum unit. The Photometric Congress in Geneva in 1896, to which Blondel's recommendations were presented, adopted the term lux, as defined in that way, that is, in the terms of the *bougie décimal* metre. We know now that the *bougie décimal* is 10 per cent. larger than the Hefner unit, but the Germans have used lux, referring to the Hefner unit at a distance of a metre. In France, the lux means the *bougie-mètre.* In this country too the term lux is used in that later sense, the *bougie-mètre,* because we have adopted a unit of the same size as the *bougie décimal* as the fundamental unit. Our candle and the *bougie décimal* are identical in size, so that we return to the original definition of the lux. Where lux is used referring to the Hefner unit, the qualification can be used "Hefner lux;" similarly in the case of the lumen, the qualification "Hefner lumen" can be used. As to the use c. g. s. and English metric units, there is nothing in the report which says that a person must use one or the other. Use can be made of which ever one is the more convenient, but the report is intended to make concrete and specific those that are used; there is no chance for confusion.

It will be noted that the report recommends illumination to be expressed in terms of lumens per unit area. For example, if the illumination is 2 lumens per square foot, it is the same as 2 foot-candles. Thus there is no chance for confusion. Similarly if the c. g. s. system is used, the illumination will be expressed in terms of millilumens per square centimetre; that is to say, 1/1000 lumen per square centimetre. It happens that the millilumen per square foot is a unit of about the same size as the foot-candle. However, there is nothing in the report to compel anybody to use either the metric system or the common English system in the expression of his results.

The suggestion by Mr. Stickney that specific consumption

should be defined is good. I presume that we should define specific consumption with reference to gas as well as electricity. This suggestion will receive the attention of the committee.

In regard to the suggestion that J be used for I, I do not know whether the members of this society would like to use J for the intensity of light or not. If they would, I am sure the committee would find no objection. The committee desires to make recommendations which will be acceptable to the practicing engineers of the society and would be very glad indeed to receive advice and instructions.

The motion by Dr. Rosa being put to vote was duly carried.

CENTRAL STATION ILLUMINATING ENGINEERING DEPARTMENT WORK AND METHODS APPLIED BY THE DENVER GAS AND ELECTRIC COMPANY.[1]

BY C. F. OEHLMANN.

The illuminating engineering department of The Denver Gas and Electric Company, consists of an illuminating engineer and his assistant. The illuminating engineer specifies the amount of illumination, number of openings or units, and style of lighting, deciding whether it shall be gas or electric, and the kind of either, and meets and advises with all consumers. The assistant does all architectural drafting, fixture designing, writes all wiring specifications, and makes and keeps all records pertaining to the various consumers, their wants and complaints.

This department has an office where architects may come for information, contractors to estimate jobs and consumers to discuss store or residence lighting, for better and more satisfactory illumination. In this office are samples of the various kinds of lamps, both gas and electric, as well as burners, shades and reflectors. These lamps and shades are not connected for service, nor is it intended to make a demonstration of what any one lamp will do, but they are simply used to explain to consumers why lamps, shades, etc., are built as they are, to explain why a tungsten lamp must be handled carefully, why a gas mantle is to be protected from rough usage, why some reflectors are more efficient than others, why a shade is necessary at all, and also to explain a few processes of the manufacture of the various lighting instruments. Everyone is interested; even explaining where the candle-power is measured from on a 16-c-p. carbon lamp excites much interest, and nine out of ten consumers seem surprised that 16 candle-power does not mean 16-c-p. end-on.

There are a great many such little demonstrations that are so easily shown consumers and create so great an impression that the above method has been found better than requiring a con-

[1] A paper presented at the Fourth Annual Convention of the Illuminating Engineering Society, Baltimore, October 24 and 25, 1910.

sumer to look into a set of booths showing comparison of good and bad illumination.

Existing conditions on the street are far better demonstrations than a set of rooms or booths built and lighted under ideal conditions. It is much easier to have a consumer visit a certain store to view the system used and allow him to draw a comparison; often a new idea is worked out on the sidewalk that gives a pleasing originality to the scheme of illumination when completed. If there were ideal conditions in each store, residence, etc., then a set of model rooms illuminated properly would be most valuable. In actual work ideal conditions are not known; they have been heard of from time to time, but yet there is not in Denver an ideal condition, from a scientific illumination standpoint. For instance, if the style of building or structure is Gothic one would not divide a ceiling into bays and show a great number of outlets or units. This condition is true of most styles of architecture, such as the Queen Ann, Classic, Greek, Renaissance, Roman, etc. So no matter what would seem scientific in illumination, and what is desired most, one must sacrifice for the "sake of art" and cut according to the cloth at hand. This result holds true, even more so in residences, churches, cathedrals, public halls, libraries, etc., and in just such places as these it is easier to blunder in designing the scheme of illumination and fixtures than in any kind of a commercial work.

There are more severe criticism and grief from inconsistent fixture designing where some particular style of architectural design has been adhered to than in any other work of the illuminating engineering department. It is known that there are three very decided purposes which characterize the three most distinct branches of the art of illumination, namely:

First: That of supplying light for carrying on such adventures or amusements as are extended into hours of semi or whole darkness. This branch includes interior illumination, such as store, residence, factories and shops.

Second: The art of scenic illumination directed for special effect and designed to produce special illusions. This branch includes stage lighting, picture and art galleries, etc.

Third: That used for what is called electrical advertising, impressive, attractive, establishing locations, etc. This branch includes window lighting, sign lighting, electrical lamp creations, such as growing flowers, illustrations of lightning, rain, fountains, etc.

Each of the above has distinct purposes and demands special attention and methods.

Keeping the above branches of illumination in mind, it will be seen that there are three essential points involved, namely: The right quantity, right quality, and the right use. Moreover there is another set of three factors, namely; the station or manufacturing end of the gas and electric business; the customer or buyer and the commercial department, or that department that must sell the output of the manufacturer and must so sell it that the consumer will not be abused and will remain a consumer for not only a few months but for a number of years and be satisfied and enthusiastic over the use of the commodity. There are thus three purposes, three principles, and three principals.

There have been too many good papers placed before this convention to be read and discussed for the present author to attempt to interest the members even for only a few moments in the purposes or principles. However it may be well to discuss the principals telling of the methods employed at Denver, in the hope of obtaining some suggestions that will improve the methods in many ways.

The illuminating engineering department of a central station is engaged in a work different from that of the consulting engineer, or that of the laboratory engineer. The consulting engineer is an authority in lamps, shades, effects and results. The laboratory engineer is all of this and in addition is the inventor for the consulting engineer. The illuminating engineer for the central station, must try, when advisable, to put into application all of the ideas of the former and the inventions of the latter, and even this is the easiest part of the work.

The consulting engineers are arranging from time to time formulas for figuring densities of illumination that simplify the work of the artist as he drafts plans and specifications for a proposed lighting installation.

The laboratory engineers in the last twenty years have made two great strides in better gas lighting; one stride is the incandescent gas mantle, and the other the inverted styles of mantle lamp. The advancement in electric lighting has been much more rapid, the arc, carbon, improved carbon, tantalum and tungsten lamps following each other so rapidly that one does not even now feel safe in designing a lighting system that should last at least three years. There are then the consulting engineer with his formulas and opinions, and the laboratory engineer with the inventions.

Though these two classes of illuminating engineers have done wonderfully good work, they have been, up until the last year or so, of very little help to the central station and the consumer jointly. The consumer and the station must be in harmony. The central stations have realized this fact and while knowing that the consulting and laboratory engineers have done a great deal of educational work among people interested in the sale and manufacture of gas and electric appliances, the consumers at large have learned very little. The central stations acknowledge this fact and have found that the best method of getting good results quickly from illuminating engineering work is to reorganize and operate an illuminating engineering department in connection with the station.

The central station illuminating engineer after having studied the science of illuminating engineering work, learns that his work is to "hold the business." The result is that the illuminating engineering department finds that it must sell to the same consumer light for as many hours out of the twenty-four as possible, in order to widen the peak load, and that to the same consumer light must be sold for as many years as possible. Thus the peak should be widened until there is no peak, and the station investment, covering mains, services, meters, etc., should be kept in actual use, during the approximate life of the station installation.

A person contemplating installing a gas or electric plant expects the plant to operate at least twenty years. No one will deny that it is better to conduct a good business continuously for a number of years with one consumer than to make investments

of service, main and meter, in order to hold an excess of business for a month or two, and then have the consumer complain of the high bill and order the meter removed and the account closed. This is a common occurrence; in fact, 70 per cent. of the illuminating engineering department's work is in the straightening out of just such bungles.

It is well known that the ideal load curve is one that shows no peak—it is also well known that such a load curve is almost an impossibility; there is sure to be a peak one slope of which occurs between dusk and dawn. The study of the load curve is of great interest to the illuminating engineering department.

Business: There are several classes of business to be sought and even fought for. One of the best is the street lighting contract, which usually covers both the maximum hours between dusk and dawn and also covers a majority of years of the life of the plant. Another is the all-night service for advertising purposes, such as window lighting, sign lighting and billboard illumination. Another is for light over the safe in the rear of stores, etc. Another is for small lamps at the base of show windows in winter months, for the purpose of preventing the formation of frost and moisture on the windows. Another is for porch lighting on an all-night arrangement. For those customers who will not accept the all-night rate, one can usually establish a two o'clock rate; this plan can be carried out by means of extension keys or other devices so arranged that patrolmen can turn on or off gas from the outside of the building. Then there is the popular midnight lighting rate, frequently used to good advantage. There is the cluster gas lamps or electric arc lamp for all-night use at livery stable entrances, garage entrances, dairy stables, hospitals and any place where wagons or vehicles leave and approach at various different hours of the night. Park lighting is another good business to secure. There are also other uses for illumination at all hours of the night that might be given some thought.

Complaints: As was mentioned in an earlier part of this paper, 70 per cent. of the work of the central station illuminating engineering department is the settling of complaints of some kind or other, usually high bills. These complaints come from

all departments of the company. When a complaint comes to the illuminating engineering department, the illuminating engineer tags it, "Hold the business." It is the complaining consumer that is the encouraging prospective consumer for the gasoline salesman. Not many gasoline lamps would be in service to-day if all gas or electric consumers had always been pleased with and enthusiastic over the results using either gas or electric light. The person complaining may be what is sometimes called a chronic kicker and by some departments considered incurable, but there are few chronic kickers in the Denver territory. The complaining person is one who usually complains about a high bill, or poor service, or both. The first step taken is to ascertain what the amount consumer has been paying during the past year. This information is marked on the complaint memorandum for future reference; the person who turned in the complaint for the consumer is then consulted and much useful information is thus obtained. A call is then made on the consumer by a member of the illuminating engineering department, who discusses with him the reasons for his complaint. He is offered the services of the illuminating engineering department free of cost. It is explained to him that if he accepts the services of the department his place of business will be measured and a drawing of his store for illustrating a suggestion or a new system of illumination will be made.

Usually in the case of so-called high bill, and often in the case of extremely poor lighting service, the store has been piped by a plumber or a gas fitter following a set of plans drafted by an architect. The average architect thinks the lighting feature of his work is of no importance. The lighting arrangement is left until the last. After drawings are almost complete, after all painting has been specified, all decorations decided upon, all ventilation arranged, all store fixtures arranged, he picks up a pencil, and says: "We will put an opening here, one there, one there, etc." He does not contemplate the illumination when deciding colors and styles of decoration, nor ventilation; he does not calculate illumination at all, but just puts in lamp openings. It is often found that the consumer's lighting system is at present just as good as it has ever been but owing to the fact that his

neighbors have improved their systems, his installation seems to have deteriorated. Frequently no difficulty is experienced in holding the business, even when the complaint is based on a high bill, for the improved lamps often make it possible to give a consumer twice, and even three times, the illumination he had obtained previously.

When the consumer consents to have the illuminating engineering department measure his store and make suggestions for better illumination, a drawing is made showing all of the walls, windows, doors, hallways, show-windows, etc. Then if the consumer contemplates any changes in the rooms or building a note is made of them and often they are arranged for on the drawings if the changes are to be made immediately. In case there is sufficient time the openings for the lamps are so arranged that when the building is changed the proper system will be in readiness. The openings that are made in contemplation of changes are plugged and no fixtures are installed. The fixtures are specially designed or selected and specifications are drawn. The drawings and specifications are submitted to the consumer and, if the plans are accepted, bids are asked on the work and taken to the consumer, and the contractor is thus selected. The work of installation is superintended by the illuminating engineering department until completed and accepted by the consumer. When the new lighting system is placed in operation the central station reaps the harvest of the work of the illuminating engineering department. No matter how bitter he may have been in his complaints, almost invariably a consumer will become very much enthused over the improved appearance of his store; he can then easily be induced to step outside of his store and compare the outside with the improved interior. He does not wait to be coaxed, but usually says, "What can we do about those windows and that sign?" It is not the actual amount of money the consumer pays that interests him, but how much he gets for his money. When the illuminating engineering department by a rearrangement or a new system, gives him three times as much illumination as before, the consumer is glad to pay the bill; the illuminating engineering department has held the business, and the consumer becomes immediately a prospective consumer for better window lighting and sign advertising.

A record is kept of the work, by taking a small kodak picture of the drawing and pasting it to a reference card, which is filed for future use. The means used for keeping this record is a cabinet card, showing the date, name, address, nature of business or building, installation made, style of glassware, ceiling height, color, decorations, size of room, watts per sq. ft., density, reasons for changing, previous installation, and remarks.

A photo of the original accepted drawing is placed on this card and filed for future reference. This card is cheap and convenient to refer to later and takes little room. The consumer often wants the original drawing for other structural work and if he so desires it is given to him, the company being released from responsibility if errors in measurement are made from the drawing, such as structural iron being short, millwork and metal ceiling not fitting, etc.

Cards are also used in keeping a record of new buildings. A record is kept of all building permits. Cards are sent to new owners, architects and contractors, offering services of the illuminating engineering department.

All representatives are given an opportunity to join an illuminating engineering class during the fall of each year, and those who join are given a series of lectures and instruction along illuminating engineering lines. They are taught to read drawings, and are instructed in a few principles of fixture designing. The object of this course is to teach the commercial men the principles of illuminating engineering, in order that they may correct small mistakes as they proceed in their work each day, when small additions and alterations are being made. They are also given information and data regarding new shades, lamps, etc., and the uses to which thay can be put.

DISCUSSION.

S. W. Ashe:—With a view to cooperating with the various central stations in illuminating engineering five kinds of educational work are being conducted at the electric lamp works at Harrison, N. J.

The first form of educational work consists of the training of a corps of college men carefully selected from various universities throughout the United States, who are daily employed in

the factory and laboratories where they are working upon the various processes of lamp manufacture. Each day, from 11 to 12, these men attend a graduate course in illuminating engineering and salesmanship in the lecture room; papers are assigned, experimental lectures are given, and the various department heads discuss the problems encountered. The work corresponds, in some respects to an apprentice course, as the men are hired at about $15.00 per week, which salary they receive for the first six months, when an increase is given to those who are most deserving.

The men will continue this course for one year; at the end of this time, they will be distributed to the experimental laboratory, factory, sales department, etc. The commercial men, who come in to the factory from the field from time to time, talk to these men so that the men become familiar with all phases of the problems of illuminating engineering and lamp manufacture.

The second class of educational work consists in the training of men to sell lamps. The men taking this course had some selling experience, but knew little or nothing about illumination or electricity in general. The duration of this course is three weeks, the men being in daily attendance from 9 to 5, except on Saturday which is a half holiday. These men work out problems, perform simple experiments in electricity, design illuminating schemes, draw plans, get data on costs of wiring, study competitive illuminants and attend the daily lectures given to the college men. At the end of three weeks they are quite familiar with all details requisite for the selling of lamps.

The third form is the training of the salesmen already in the field. Once each year these men are brought back to the factory, and are given an advanced course and an opportunity to review their elementary knowledge. In this advanced course the men are trained in the art of giving lectures, learn to operate the lantern and to perform experiments in public, so that they can form their own little educational centers, taking part in such conventions as happen to meet in their territory and giving lectures to their assistants and to the local lighting people.

The fourth form of educational work consists in the training of a corps of experienced men, who are attached to the home office,

as specialists on various subjects, such as sign lighting, automobile lighting, street lighting, residence lighting, store lighting, etc. These men are prepared at all times to attend conventions, to give experimental lantern slide lectures to such companies or associations as may be affiliated in a business way with the lamp company. These men are to be specialists in their individual subjects, so that they may be able to grasp all its phases. By allowing them to give lectures to the various companies they get into contact with actual commercial conditions and thus become thoroughly familiar with the various problems confronting central station companies.

The last form of educational work consists of the training of the factory and office forces. This work is in the nature of an experimental lecture course covering the elements of illumination and elements of electricity. Two lectures per week are given to these people during the noon hour.

The great advantage of all of this educational work in that it all passes through one common center of distribution and owing to the proximity of the factory to the sales department, the element of cooperation will be utilized to its highest extent. The above work has been carried on for about a year, but has recently been reorganized and expanded.

Mr. A. J. Marshall:—In one part of the paper the author says: "The average architect thinks the lighting feature of his work is of no importance. The lighting arrangement is left until the last." The convention here is of illuminating engineers and there is probably not an architect in the house and yet the architect is the person who controls the application of light in a great number of the buildings. While I do not say that the architect has a comprehensive knowledge of the application of light, I do think he knows a whole lot more about the effects than we do as engineers. The architect is needed in this Society but just such remarks as used in this paper have kept him out of the Society. We refer to him as the "know-nothing architect." It seems to me this is rather egotistical on the part of the engineer. We should give the other fellow credit for knowing something about the work. By showing the architect that his side is appreciated his cooperation can be obtained for the Society. I should like

to see architects in this Society, but they will not come in as long as we continue to be antagonistic as here and elsewhere indicated.

President Hyde:—It is an interesting fact that yesterday the president of the American Institute of Architects sent in his application for membership in the Society.

Mr. R. B. Ely:—In making plans for illuminating stores does the author submit specifications for the piping in the gas installation and wiring specifications in the electrical installation?

Mr. Norman Macbeth:—While in Denver this summer I learned to admire the methods there employed. One excellent plan is the showing of existing installations to prospective customers. I do not know any better way of satisfying a consumer than by this method. It is not necessary always to show the particular kind of installation that one would advise for the consumer's building, but rather to have him meet the old customer who will tell him that after all the difficulties he had experienced with his previous installations, this department not only successfully straightened everything out but vastly improved his illumination at the same time. The prospective customer will usually say: "Well, I will leave this matter in your hands" whereas had it been merely a question of seeing a different kind of installation he might say: "Well I would not care to have that kind of lamp or fixture in my place."

The plans and specifications given out in Denver, particularly the plans, are very striking. Use is made of water color wash drawings. These are equally attractive as the colored prints sometimes furnished by an architect of the front of some very elaborate building. This method cannot but make a strong impression on a consumer.

I believe that I can answer Mr. Ely's question. The company not only gets out specifications for gas piping and electric wiring but specifications for other structural work, so that the work of the department is largely a general engineering proposition.

As pointed out by the author, a central station must educate its salesmen. Nine-tenths of the installations are sold by the salesmen and when the work comes to the illuminating engineer he is often powerless to make either changes or suggestions.

The salesman will already have agreed upon the number of fixtures and the kind of lamps to use and it is, therefore, of extreme importance from the standpoint of good service that the salesmen be properly trained and brought to appreciate the value of the illuminating engineering department that they may work with it rather than against it.

Mr. R. S. Hale:—What is the average cost in making the drawings? What proportion of the customers take advantage of the drawings each year?

Mr. E. B. Rowe:—In connection with that last question I ask how many specifications per day are turned out by the illuminating engineering department, that is, by the engineer and his assistant.

President Hyde:—Mr. Williamson, who read the paper for the author, will close the discussion.

Mr. Williamson:—In Denver it has been found that so far as the central station is concerned, the better the installation, the easier it is to get more business, and that it pays to put in wiring and piping specifications and to see that the work is done properly. A well illuminated store is the best salesman for the illuminating department. Every time a new installation is put in, it is always followed by others for merchants on the same street in that same locality who, without solicitation, express a desire for something a good deal like the installation of their neighbor. No charge is made for the drawings and specifications; all the work is given gratis. Concerning the cost to the company, I don't know. A sketch artist is employed at $3.00 a day, and he gets out an average of about one set of specifications and drawings per day.

THE EFFECT OF LIGHT ON THE MOVEMENT OF THE LOWER ORGANISMS.[1]

BY S. O. MAST.

By "lower organisms" we mean the simpler of the living beings, mostly microscopic forms. Of these there are hundreds of different kinds, many more than could be even named in the time at my disposal. I shall consequently confine what I have to say largely to one or two of these creatures.

Light has either directly or indirectly, a very profound effect on all living things, including the human being. Much has been written in the past years concerning the germicidal effect of light. It is known that the shorter rays, the blue, the violet and the ultra-violet, kill many of these germs, (bacteria and some other lower organisms.) However, there are many lower organisms that are somewhat more complicated than the bacteria, and while they may not be killed as readily as the germs mentioned, it is found that intense light, such as direct sunlight, almost invariably has an injurious effect on them. If the light is too intense, they cannot withstand its effect for any great length of time. It is assumed that the injury is due to a breaking down of the protoplasm, a photochemical change, a simplifying of the chemical substances within the living organism.

Light is, however, by no means always injurious. It may have a synthetic as well as an analytic effect on chemicals. Simple compounds as for example, carbon dioxide and water are united to form the carbo-hydrates and other compounds. $[n(H_2O) + n(CO_2) = n(CH_2O)$, sugar, starch, etc. $+ n(O_2)]$. This takes place only in the presence of light and the green substance, chlorophyll, that is found in leaves and other plant structures and in many of the lower organisms.

Most of us do not fully realize that, if it were not for this synthetic process, the building up of the simpler substances into more complex, which, as stated before, takes place only in the presence of light, no living being could long exist on this earth, for every organism, plant as well as animal, must have complex

[1] A lecture delivered at the Baltimore convention of the Illuminating Engineering Society, October 24, 1910.

chemical compounds as its food material, and these are at present synthesized only in the presence of light and chlorophyll embodied in living matter. Green plants can manufacture their own food, but all other plants and nearly all animals are not able to do so. They are dependent directly or indirectly upon green plants for food. Let me illustrate. Floating in nearly all of the waters of the seas near the surface are innumerable microscopic, green plants of various kinds. Each one of these minute specks of living matter contains chlorophyll and is in reality a synthetic laboratory in which, in the presence of light, the complex food substances necessary for life are manufactured from chemical elements and simple compounds. The complex compounds thus formed are taken in by myriads of small animals which feed on the minute plants, and some of these compounds are passed through larger animals,—minnows and small fishes, which devour the small animals, to still larger fishes and other creatures which in turn find their way into the stomachs of the next size, and so on, until the largest are reached. Thus even those fishes which live entirely on other fishes, carnivorous creatures, are dependent upon minute green specks of living substance for the manufacture of essentials in their food supply, and the motive power in these factories is light.

If the light is too intense, it is as already stated, injurious to most of the lower organisms. If it is too weak the synthesis of food substance is interrupted. It will readily be seen then that it is of the greatest importance for these organisms to be able to aggregate in light of the proper intensity, not only for their own welfare, but also because of the dependence of many other beings on them for food. And, strange as it may seem, these simple organisms without eyes have the power to do this; when the light gets intense they go down; when it gets weak they swim to the surface. But what interests us mainly at present is how they regulate their movements not only in attaining regions of proper illumination but also in remaining in these regions. This is found to differ in different species. I shall have time to describe the regulation of movement in only two, one of which is known as Euglena, the other as Amoeba.

Euglenas are small cigar-shaped green organisms, scarcely 0.1

millimeter in length and but little more than 0.01 mm. in diameter —quite too small to be seen with the naked eye, but most beautiful creatures as seen under the microscope. Attached to one end there is a thread-like protoplasmic projection nearly as long as the body of the organism, and it is by means of this that the

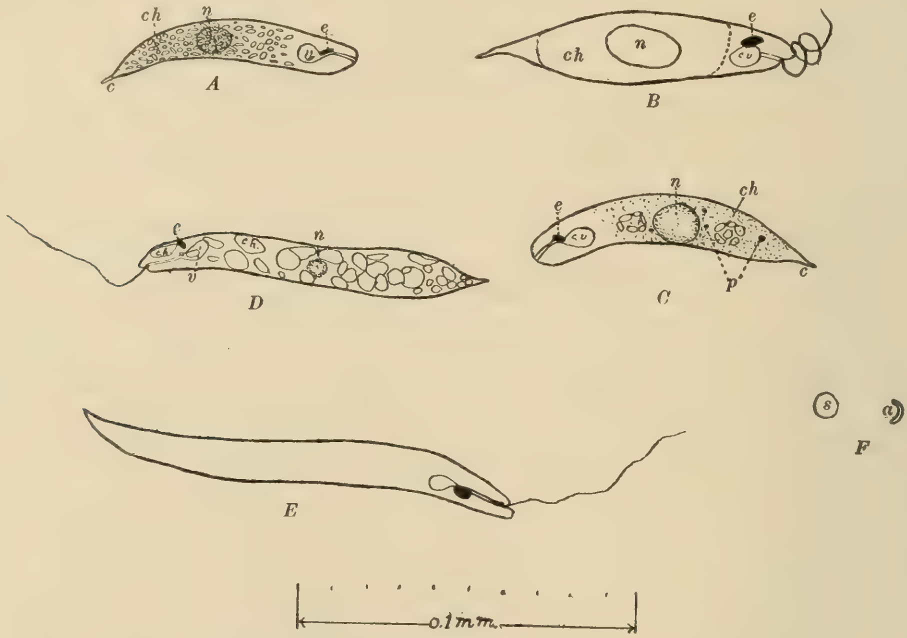


Fig. 1.—Euglena, showing general structure of different forms.

A, C, Euglena in crawling state; B, probably a form of E. viridis; D, E. E. deses; *e. s.*, pigment-spot; *c. v.*, contractile vacuole; *c. h.*, green bodies containing chlorophyll, space in B limited by dotted lines well filled with small ones; *n*, nucleus; *c*, caudal spine; P, pigment granules which appear to be composed of same substance as pigment-spot,—these were found in only a few specimens; E, shows typical curvature toward dorsal surface while swimming in direction indicated by arrow; *f*, pigment-spot highly magnified; *s*, surface view; *a*, view from anterior end. The convex surface is directed outward. *mm.* projected scale with the same magnification as the Euglenas. All outlines were made with camera from specimens killed in iodine. Contractile vacuoles and nucle were sketched free hand from living specimens.

Euglenas swim. During this process the thread-like projection extends forward and has a corkscrew motion by means of which the organisms are literally pulled through the water as they turn on their long axes. Somewhat below the surface near the anterior end there is a small disk-shaped mass of brownish pigment which is opaque to all of the shorter waves of light, the green, the blue and the violet. Sometimes the Euglenas lose their lash-like projection and then they proceed by crawling on the bottom. In this state, just as in the free-swimming state, they rotate on

their long axes as they progress but they ordinarily move much more slowly. Their crawling rate of movement is seldom more than 0.3 mm. per minute.

Euglenas are found in great numbers in the open sewers about Baltimore. They usually collect on the bottom, frequently in such masses as to give the water a deep green color. If a large number are mounted in a dark field which contains a light area of moderate intensity, they aggregate in the light in the course of a very few minutes, frequently to such an extent as to form a dense green mass. How do they get into this area of light and what keeps them there?

Under some conditions they get into the illuminated area accidently, that is, by swimming about at random; under others, they orient and swim directly toward the light from all directions. In either case they remain because whenever they reach the edge of the area of light so as to cause a decrease of intensity on the anterior end they are stimulated and consequently stop and turn in another direction. This response is repeated every time they come to the edge of the field. Thus the illuminated area acts like a trap. The Euglenas can get in without any trouble, but every time they reach the edge on the way out they are turned back by the stimulus produced by the decrease of intensity. But how is it that they can orient or turn toward and swim directly into the area of light? Before answering this question let me say a few words more on their aggregation. If in place of having a spot of light of moderate intensity surrounded by a dark field, it is surrounded by intense light as, for example, direct sunlight, it is found that the Euglenas still collect in the moderately illuminated area. Exposure to very intense light causes a reversal in all their reactions, so that they no longer respond when they pass from regions of higher into those of lower intensity as they formerly did, but just the opposite, and if they orient at all they face and swim toward the darker regions, instead of the lighter, and under such conditions they collect in the weaker light in place of the stronger; the area of moderate illumination acts like a trap just as in the case of the dark field save that now it is an increase in place of a decrease of intensity which prevents the creatures from leaving the area.

It is evident that such a reversal in reactions is of prime importance to these creatures. It can be seen even more clearly if Euglenas are mounted in horizontal rays of light from a single compact source. Under such conditions they orient and swim fairly directly toward the light until they have been exposed for some time and the intensity becomes very high, then they turn about and swim as directly in the opposite direction until they have reached and have been in weaker light for a short period, when they become positive again. The tendency under these conditions is also to aggregate in light of moderate intensity.

But let us return to the question of orientation and consider the Euglenas in the crawling state since the free-swimming specimens move so rapidly that it is almost impossible to see the details in their reactions under the microscope. If the light intensity is suddenly decreased after specimens are oriented and moving toward its source, they respond with a definite and specific reaction which consists of a sharp bending toward the ventral surface. Precisely the same reaction is found in the process of orientation. Just what occurs during this process can best be seen by arranging two sources of light so that the rays cross at right angles under the microscope and then after the Euglenas are oriented in the light from one source suddenly exposing them to that from the other so as to illuminate one side. Under such conditions the direction of the rays can be rapidly changed through 90° as often as desired by alternately shading the two sources of light. The details in the process of orientation will be more readily understood by referring to the accompanying figure in connection with the following description.

If the ventral surface, the surface opposite the pigment-spot, faces the source of light after the direction of the rays is thus changed, there is no immediate reaction. The Euglenas continue on their course as though no change had taken place until the rotation on the long axis carries the dorsal surface over into a position in which it faces the light. As soon as this surface, the surface containing the pigment-spot, faces the light there is a definite reaction. The Euglenas respond just as they do when the intensity is decreased, they turn the anterior end toward the ventral surface more or less sharply, that is, away from the source

of light, but they continue to rotate so that the ventral surface soon faces the light again, but it is evident, owing to the curvature in the body, that the anterior end is now directed more nearly

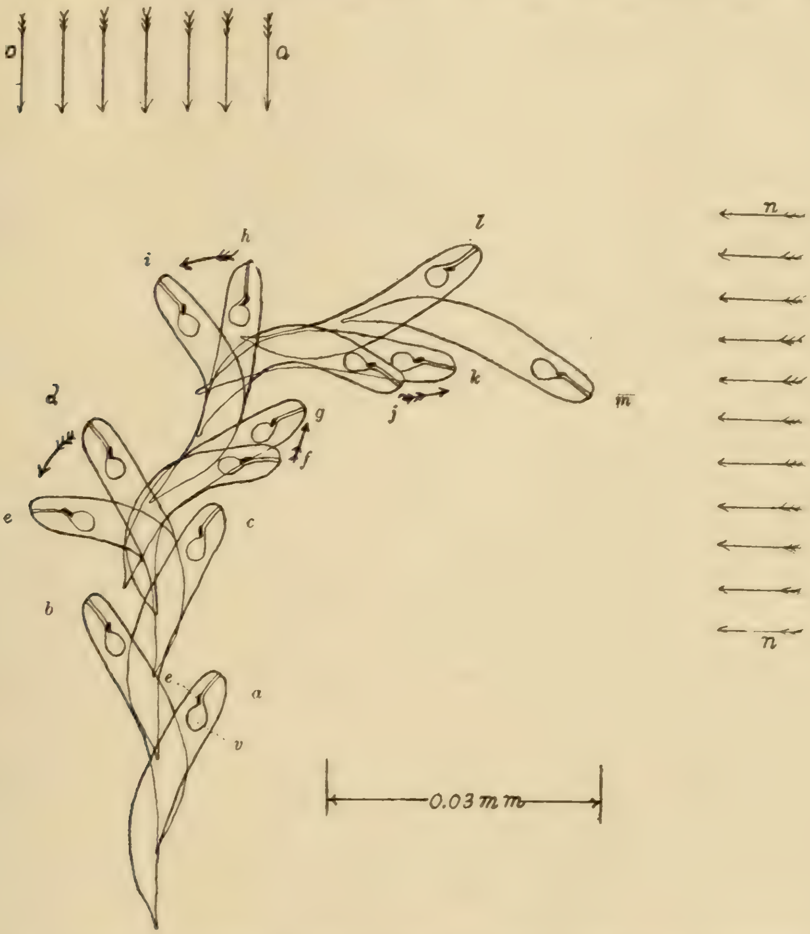


Fig. 2.—Euglena in crawling state showing details in process of orientation.

c. v., contractile vacuole ; *e. s.*, eye-spot ; *n*, *o*, direction of light; *a-c*, positions of Euglena with light from *n* intercepted; *c-m*, positions with light from *o* cut off so as to change the direction of the rays. If the ray direction is changed when the Euglena is in position *c*, there is no reaction until it reaches *d*. Then it suddenly reacts by bending away from the source of light to *e*, after which it continues to rotate and reaches position *f*, where it gradually straightens to *g*, and rotates to *h*, when the pigment-spot again faces the light. The organism is again stimulated and bent to *i*, from which it proceeds to *j*, etc., to *m*, and it is practically oriented. If the ray direction is changed when the Englena is at *d* it responds at once and orients as described above. If the intensity from *n* is lower than that from *o* the organism responds at once when the ray direction is changed no matter in which position it is.

toward its source than it was when this surface faced the light during the preceding rotation. While in this position, the body is somewhat straightened so that the anterior end is not carried back as far during the following rotation, and when the dorsal

surface comes to face the light it is directed more nearly toward its source than it was when the organism was in this position before, as represented in Fig. 2. This reaction is repeated during each complete rotation. Every time the pigment-spot becomes more strongly illuminated the organism responds by bending, and when it becomes shaded the organism gradually straightens out and resumes its normal form again; thus the anterior end becomes directed more and more nearly toward the source of light until the organism reaches an axial position in which the pigment-spot is no longer exposed to sufficient changes in illumination during the process of rotation to cause a bending reaction. The organism therefore continues in this direction, that is, more or less nearly toward the source of light. Orientation is frequently brought about in two or three rotations. It is clear that during this process light does not act continuously as an orienting stimulus.The organism responds with reactions leading to orientation only when the dorsal side is turned toward the source of illumination, not when the ventral side is exposed. And it should be emphasized that the first movement in the response is a *bending away from the source of light,* toward which it later becomes oriented.

It is evident from the above description that turning into such a position that the pigment-spot faces the source of light produces a stimulation which results in a definite reaction. In this reaction the organism always bends the anterior end toward the ventral surface. It appears at first thought as though this reaction were due to the illumination of the pigment-spot. This is however not true, for, as pointed out above, the response which leads to orientation is precisely the same as that caused by a decrease in illumination without any change in the direction of the rays. It appears probable then that the orienting response is due to a decrease of intensity of some sort. It is known (1) that the anterior end of the Euglenas is more sensitive than the rest of the body; (2) that the shorter waves of the spectrum are most efficient in stimulating them; and (3) that the pigment-spot is opaque to these rays. The orienting stimulus is probably due then to the decrease of intensity on the anterior end caused by the

shadow of the pigment-spot when this is turned toward the light, not to the illumination of this spot.

It is assumed that many of the responses of this organism to light are rooted in the effect of light on the process of photosynthesis,—the synthesis of complex chemical compounds in light. This as previously stated, takes place only in connection with chlorophyll. Euglenas swimming into a shadow, however, respond and turn back into the light as soon as the anterior end which often contains no chlorophyll becomes shaded, that is, before the green part which has to do with photosynthesis reaches the shadow at all. If the assumption is true, it is evident then that this organism, like the wise among its more complicated relatives, the human beings, does not live and act entirely in the present, nor does it respond entirely with reference to the past and present, but also with reference to the future. It is not primarily interested in avoiding the condition of illumination which induces the response, but it is interested in avoiding the condition which would follow if it did not respond when it does. It is of no apparent importance to the organism to keep the colorless anterior end illuminated, but it is of the greatest importance to keep the green part back of this end in the proper intensity of light. All of the reactions are however no doubt associated with chemical changes within the organism. Just what these chemical changes are and how they are regulated are fundamental problems for the scientist of the future.

I shall refer only very briefly to the movements, particularly the movements which result in orientation of the organism known as Amoeba. An amoeba consists of a minute mass of jelly-like protoplasm, rarely large enough to be seen with the naked eye. It lives in slime on the surface of stagnant water or in ooze at the bottom, and feeds largely on bacteria and microscopic green plants, which it engulfs entire by flowing around them. It is all mouth; food may be taken in practically anywhere on the surface.

It has no locomotor appendages, but flows or rolls along over the surface on which it moves, sending out blunt projections called pseudopods, and withdrawing them as it proceeds as represented in Fig. 3. Distinct protoplasmic currents in the direction of locomotion are clearly seen during this process. The

pseudopods appear to be formed by a weakening of the surface at the point of formation, and a consequent rapid flow in that

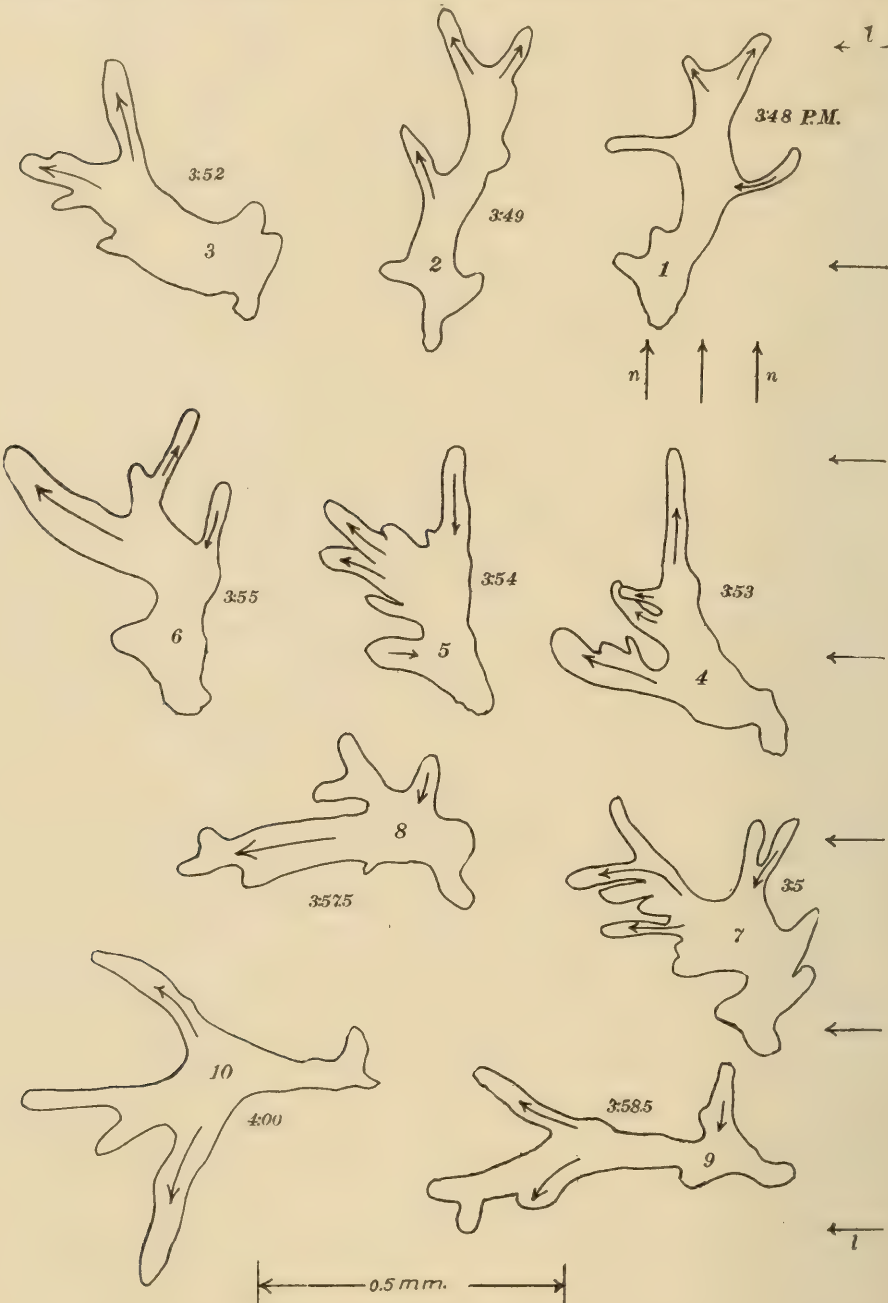


Fig. 3.—Camera drawing representing different stages in the process of orientation in Amoeba proteus.

l, Amoeba oriented in light; *l'l'*, 2'-9 successive positions after exposure to light *ll*, time indicated on each. Arrows represent the direction of currents of protoplasm in the pseudopods. In those which do not contain arrows there were no noticeable currents at the time the sketch was made. *ll* aud *l'l'*, direction of light; *mm*, projected scale indicating the actual size of the Amoeba.

direction. Concerning the mechanics and regulation of the movement in this creature but little is as yet known. But it is known that it responds to touch, electricity, chemicals, heat, light, etc.

Amoebas contain no chlorophyll. They tend to avoid light, especially if it is strong. If exposed to direct sunlight they orient fairly accurately and move from the source of light. The reactions involved in the process of orientation as seen in a given individual are accurately represented in Fig. 3. By referring to this figure it will be seen that when, without changing the light intensity, the direction of the rays is suddenly changed so as to illuminate one side of the creature, all movement toward this side is inhibited, and gradually more and more pseudopods are sent out on the opposite side, until the organism is oriented and moves from the light. The inhibition of movement on the illuminated side is no doubt due to the increase of the light intensity there. Just why this should cause cessation of movement except in so far as it may be injurious is not known. And there is no evidence indicating that it is injurious, for after a few moments' exposure even in very strong light, movement usually begins again. If intense light is thrown on active specimens all the movement in the whole organism stops at once. This is particularly marked if the light is rich in the shorter rays. Red and yellow have very little effect on the movement. After a few moments' exposure currents are again seen in the protoplasm and the creatures gradually become active.

In closing I wish to call your attention to an interesting point brought out in the reaction of Amoebas in avoiding intensely illuminated areas as represented in Fig. 4, which shows the process as seen in an individual sketched at the time of observation. By referring to this figure it will be seen that after one pseudopod came in contact with the illumination and was stopped, the amoeba did not at once proceed in the opposite direction so as to avoid the light, but sent out other pseudopods at only a slight angle with the first apparently trying to get around the object in this way. The character of the response did not change after the first pseudopod came in contact with the light, nor did it change after the second and third came in contact with it. But after the fourth became exposed the direction of motion was nearly re-

versed. This indicates that the reaction was modified, that after having been stimulated in a given way a few times the creature changed its method of response. Or, to put it in popular language, after the organism had made several attempts to avoid the light in going in a given direction and failed, it tried another direction. A change in response of this sort is what is usually

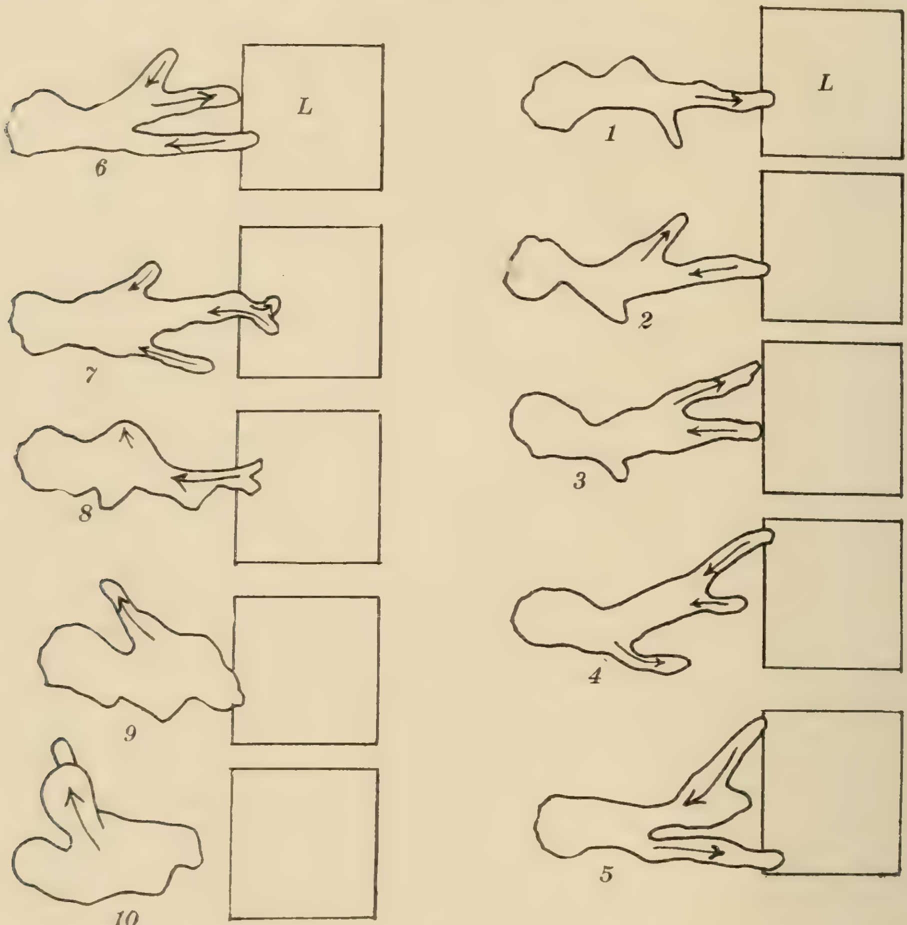


Fig. 4.—Sketches representing the reactions of an amoeba proceeding toward an intense areas of light, the rays of which were perpendicular to the slide.

L, field of light formed by focusing a limited section of a gas mantle on the slide. 1′-10, successive positions of the amoeba a little less than one half minute apart. Arrows indicate direction of currents in pseudopods.

observed in higher animals during the process of learning; and while I do not wish to be understood as advocating that Amoebas, naked specks of protoplasm, can hope to attain much honor or glory in the way of scholarship, their reactions seem to indicate that they possess at least some of the fundamentals necessary to attain knowledge.

DISCUSSION.

Dr. P. W. Cobb:—The organisms described, in using their function of light sensitiveness, act very much in general as the human being does. They look out for the main chance. As is well known, the larger organisms are composed of millions of smaller organisms known as cells, which are built up into tissues and form the body. The progress of study in the medical sciences has led men, first, before the microscope was invented, to consider the gross appearances; medicine consisted then in examining the symptoms externally—and later, in dissesting the dead body and noting the gross appearances of the diseased organs. When the microscope came to be applied, the cell theory was originated and received support; then the science of disease became a study of disease processes in cells. It has been the same way with physiology. More and more the tendency is to look to the influence on cells, of changes in conditions of their environment for instance, as regards chemical differences. In the case of these and similar organisms, the addition of slight amounts of chemical substances to the water in which they live has been tried and the effect on the organisms noted. Of course, in the body of the larger organisms there is the specialization of various groups of cells for various purposes. Certain cells, muscle cells, have the function of muscular contraction, putting forth energy; bone cells which lie within the bone in small spaces, have the function of building bone tissue, and so on. There are certain cells in which the function that Professor Mast has explained is specialized, and these are the light-sensitive cells of the retina. As the euglena responds by varying its motion in a definite way with respect to the direction of the rays of light which fall upon it, so I think we can say in a much more complicated way the entire organism, man himself, regulates his motions by the way light falls on the cells in the retina, that is, on the visual cells. However, there are only two sets of cells so far as I know that respond directly to the light that falls upon them. The cones, which are one of the sets of light receiving organs, respond by moving toward the light, and parts of certain pigment cells just back of the retina move with the spaces between the rods. An eye which has been exposed to the light

shows the cones and pigment as having moved towards the surface of the retina exposed to the light; and a dark eye— that is, the eye of an animal kept in the dark for an hour, and killed in the dark—does not show this. This function, the movement, in response to light stimulation and changes in the light stimulation of these retinal cells, constitutes in the higher organisms a process which involves miilions of cells. I have reference here to those automatic movements of pupillary change, accommodation and movements of the eyeball as a whole. In this little organism which is composed of one cell only, this function of response to light is still found. In the one cell in this case there are beginnings of all the functions that are found in higher organisms, and it is to be noted that the light receiving function is not excepted. From this standpoint the paper is very interesting.

Mr. C. O. Bond:—Will Professor Mast tell us the effect of different colored lights on these little organisms? In his diagram he showed that they moved collectively from a place that was too dark for them, and afterwards moved from one which was too light for them; but after a time they reached a fixed point,—one which was satisfactory to them. Ishould like to know if any means were taken for measuring the distance of that point from the light source to know what intensity was found best, and whether that value would apply to the group of them or to each individual organism. I think the lecture is most interesting as describing the original portable photometer.

Mr. F. J. Pearson:—Does Prof. Mast consider the effect of the light as exercising any dynamic resistance to the movement of the organisms in their propulsion through the water? Is the bending contortion of the micro-organisms intended to eliminate the resistance to their progress through the water?

Professor Mast:—As far as I know light in itself does not change the friction in the water. Heat does however, and the light that is absorbed by the water, of course, is changed into heat, and in that way it undoubtedly has some slight effect on friction. But this has very little to do with the movements of the lower organisms except in so far as differences in temperature may produce currents which carry them.

The effect of color has been quite thoroughly studied. The light rays that have the greatest stimulating efficiency in the organisms, are those below the blue, the blue and violet in particular; when one gets to the shorter rays in the violet, then the effect is not quite as great. The greatest stimulating efficiency for a given amount of energy is then between the blue and the violet.

There is great individual variation in all of these organisms. One may respond in a definite way at one particular time and another one may respond in a different way, and all of them have the power to adapt themselves to some extent to their environment. If they are kept in a high light intensity for a long time—that is not too high, but just high enough so they live in it—their optimum usually becomes higher; that is, they become, so to say attuned to a higher light intensity. Certain changes take place within them. Perhaps more pigment is deposited, so that less light gets into them; at any rate, they can live in a higher light intensity. If these organisms were kept, say, in a ten candle-power light for a long time, and then suddenly exposed to a thousand candle-power, it might kill them; whereas, if they were kept in a hundred candle-power for a long time and exposed to a thousand candle-power, it might have no effect on them. The amount of light then that is best suited for the well being of these organisms at a given time depends upon the amount to which they have been accustomed. There is however, considerable individual variation in this matter.

President Hyde:—What is the effect of ultra-violet light of extremely short wave-length, when the organisms come close enough to the surface, so that they are exposed to radiation of sufficient intensity?

Professor Mast:—Ordinarily ultra-violet is injurious to these organisms.

President Hyde:—Do they deliberately go away from it?

Professor Mast:—This has not been worked out; it is extremely difficult to work in ultra-violet light, because our eyes cannot see the organisms in it.

ILLUMINATING ENGINEERING SHEETS FOR THE CALCULATION AND RECORDING OF DATA.[1]

BY J. S. CODMAN.

Although in the last four years since the formation of the Illuminating Engineering Society in 1906, there has been a great development of the mathematical theory of illumination, and although great progress has been made toward facilitating calculations in accordance with this theory by means of tables of illumination, special charts and slide-rule calculators, specially designed platting paper for photometric curves, and by the publication of special data in regard to various lamp sources; nevertheless, the labor of making calculations is still an obstacle to a very extended use of the theory in practical work. It is generally the case to-day that small problems in illumination are not solved on scientific principles, since they do not warrant the time necessary for the calculations. The writer believes that the engineering sheets presented herewith, will prove to be of great assistance toward increasing the usefulness of the mathematical theory of illumination in practical work.

In presenting these sheets, the writer desires to take the opportunity of expressing his appreciation of the suggestions and co-operation of Mr. E. B. Rowe, and to thank Mr. J. A. Spears for his assistance in checking the values given. It is believed that the latter are absolutely correct as far as they go, but they have not been carried further than three significant figures, which is as far as would seem to be warranted.

The sheets described are designed to have three functions:—

First:—To serve as a convenient means of recording the results of photometric tests.

Second:—To facilitate the making of calculations from the test data recorded, and

Third:—To serve as a convenient record of such calculations, so that repetition of work done will, to a great extent, be avoided.

[1] A paper presented at the Fourth Annual Convention of the Illuminating Engineering Society, Baltimore, October 24 and 25, 1910.

There are two sheets described which may be called the "angle" sheet and the "distance" sheet. The former is first explained in detail and the latter will then need only a few words.

THE "ANGLE" SHEET.

It will be noted that at the top of the sheet there is a space for description of the lamp, a space for the description of its equipment, and other spaces the purposes of which are evident. The remainder of the sheet, with the exception of a portion at the bottom reserved for obvious purposes, is divided into vertical columns and an explanation of each column follows:—

Column 1. Angle Φ. In this column is given the angle made with the vertical from 0° to 180°, in five degree steps.

Column 2. Distance from foot of perpendicular. This column gives the values of the tangent of angle corresponding to the values of the angle opposite in the first column, and since the height of lamp is unity, (see top of sheet) these are also the values of the horizontal distance from the point directly under the lamp to the points illuminated by the light at different angles.

For angles greater than 90° it is assumed either that the points to be illuminated are above instead of below the lamp, or that the lamp is inverted so that the upward rays become downward rays.

Column 3. Candle-power. In this column it is intended to put the values of the candle-power ascertained from test, and when this is done, the sheet is ready to be filed away until such time as it may be convenient to make calculations. If values of candle-power additional to those from the test are desired, the usual photometric curve can be constructed from the test values and the additional derived values can then be entered in the table. After the candle-power values have been entered, the various illumination and other values indicated can be calculated when desired, and at the same time a permanent record will be obtained of all calculations made.

Column 4. $Cos^2 \Phi$. This column gives the values of the square of the cosine of the angles corresponding in the first column, and these values serve as constants for calculating the values of the normal illumination for insertion in the next column.

LAMP ....

EQUIPMENT ....

DATA FROM ....

CALCULATED BY .... HEIGHT OF LAMP—*UNITY* DATE ....

ANGLE Φ	TAN Φ or DISTANCE from PERPENDICU'R	CANDLE POWER	$\cos^2 \Phi$	NORMAL ILLUMINATION	$\cos^3 \Phi$	HORIZONTAL ILLUMINATION	LUMEN CONSTANT	LUMENS	AREA OF RING	AVERAGE ILLUMINATION	UNIFORMITY	LUMEN SUMS	LUMEN SUMS LAMP UNEQUIPPED	PER C'T. EQUIPPED TO TOTAL FLUX	AREA OF CIRCLE	AVERAGE ILLUMINATION	UNIFORMITY
0	0.0		1.000		1.000												
5	.0875		.992		.989		.0955		.0977						0977		
10	.176		.970		.955												
15	.268		.933		.901		.283		.319						.416		
20	364		.883		830												
25	.466		.821		.744		.463		631						1.05		
30	.577		.750		.650												
35	.700		.671		.550		.628		1.17						2.21		
40	.839		.587		.450												
45	1.00		.500		.354		.774		2.25						4.46		
50	1.19		.413		.266												
55	1.43		.329		.189		.897		4.96						9.43		
60	1.73		.250		.125												
65	2.14		.179		.0755		.993		14.3						23.7		
70	2.75		.117		.0400												
75	3.73		.0670		.0173		1.058		77.3						101		
80	5.67		.0302		.00524												
85	11.4		.00760		.000766		1.091		∞						∞		
90	∞		0.000		0.000												
95	11.4		.00760		.000766		1.091		∞						∞		
100	5.67		.0302		.00524												
105	3.73		.0670		.0173		1.058		77.3						101		
110	2.75		117		.0400												
115	2.14		.179		.0755		.993		14.3						23.7		
120	1.73		.250		.125												
125	1.43		.329		.189		.897		4.96						9.43		
130	1.19		.413		.266												
135	1.00		.500		.354		.774		2.25						4.46		
140	.839		.587		.450												
145	.700		.671		.550		.628		1.17						2.21		
150	.577		.750		.650												
155	.466		.821		.744		.463		.631						1.05		
160	.364		.883		.830												
165	.268		.933		.901		.283		.319						.416		
170	.176		.970		.955												
175	.0875		.992		.989		.0955		.0977						.0977		
180	0.0		1.000		1.000												

CRITICAL ANGLE	ABSORPTION				
	MEAN LOWER HEMISPHERICAL CP				
	MEAN UPPER " CP				
	MEAN SPHERICAL CP				

NOTE VALUES IN THE COLUMN OF "LUMEN CONSTANTS" AND IN ALL FOLLOWING COLUMNS ARE PLACED OPPOSITE THE CENTER OF THE TEN DEGREE ZONE TO WHICH THEY APPLY.

FOR ANGLES BEYOND NINETY DEGREES THE PLANE OF ILLUMINATION IS ASSUMED TO BE ABOVE THE LIGHT UNIT.

Fig. 1.—"Angle" sheet, blank.

Column 5. Normal Illumination. The normal illumination at a point is found from the formula.

$$\text{Ill.} = \frac{\text{candle-power} \times \cos^3 \Phi}{(\text{height})^2},$$

and since height is taken as unity, we can, therefore write down in this column the values of the normal illumination by finding the product of the corresponding values in the third and fourth columns; that is, the values of candle-power and $\cos^2 \Phi$. When the values for any other height than unity are desired they can readily be calculated from the "unity" values recorded on the sheet, by dividing by the square of the height in whatever unit this height is expressed, and the result will be in foot-candles, meter-candles or lux, yard-candles, etc., as the case may be. If desired to keep a permanent record of these values, another sheet can be taken for the purpose with the new height inserted instead of unity and the remainder of the sheet can be left blank.

Column 6. $\text{Cos}^3 \Phi$. The values of the $\cos^3 \Phi$ given in this column are the constants for obtaining the values of the horizontal illumination for the seventh column.

Column 7. Horizontal Illumination. All that has been said above in regard to normal illumination values applies to the values of the horizontal illumination to be entered in this column, except that the values of the $\cos^3 \Phi$ are used instead of those of the $\cos^2 \Phi$, in making the calculations.

Column 8. Lumen Constant. It has been shown by a number of writers (see Wohlauer, "Illuminating Engineer," Feb., 1909, page 657) that the flux of light in lumens through any zone of the sphere determined by two angles with the vertical, is given by the following formula:—

$$F = 2\pi L (\cos \Phi_1 - \cos \Phi_2),$$

where Φ_1 and Φ_2 are the the two determining angles and L is the mean value of the candle-power between these angles. If the zone taken is a small one, the candle-power at the angle bisecting the zone can be assumed to be the mean candle-power. On these sheets this assumption is made, as the zones considered are ten-degree zones. The "Lumen Constant" on the sheets is the value $2\pi (\cos \Phi_1 - \cos \Phi_2)$, and this value, multiplied by

the candle-power value opposite it, gives the flux in lumens for that ten-degree zone. For example, the value of the "lumen constant" opposite angle 35 degrees is 0.628 and this value multiplied by the candle-power at this same angle gives the lumens for the zone between 30 and 40 degrees.

Column 9. Lumens. These values can be ascertained for each zone by multiplying the "lumen constant" by the candle-power as above stated.

Column 10. Area of Ring. By "area of ring" is meant the area of the ring in a horizontal plane at unity distance below or above lamp, of which ring the width is subtended by the difference between the angles determining a zone. For instance, the ring of which the width is subtended by the difference between the angles 10 and 20 degrees with vertical, has a certain area which can be calculated from the following formula:—

$$A = \pi \tan^2 \Phi_2 - \pi \tan^2 \Phi_1,$$

where Φ_2 and Φ_1 are the angles with the vertical determining the zone, in this case 20 and 10 degrees. These area values are given on the sheets in this column and are of use in obtaining the values in the next column.

Column 11. Average Illumination. The values to be placed in this column are those for the average illumination over the rings the area values of which are given in the preceding column. These values can be obtained by dividing the flux in lumens received by each ring, by the area of the ring; that is, by dividing the values in Column 9 by those in Column 10, and with the resulting values permanently recorded, corresponding values for other heights than unity can be calculated by simply dividing these values in the table by the square of the height in question.

Column 12. Uniformity. It is intended to place in this column certain values which will serve as an indication of the uniformity of the illumination over the corresponding ring, and it is suggested that each of these values be expressed in per cent. of the ratio of the minimum to the maximum value of the horizontal illumination. The minimum and maximum of each ring would be found from Column 7 "Horizontal Illumination" with sufficient accuracy for practical purposes, since in Column 7

would be recorded three values of the horizontal illumination for each ring determined by a ten-degree zone; these three values are those at the inner edge, the center and the outer edge of each ring.

Column 13. Lumen Sums. This column is provided for recording the flux in lumens through the zones 0° to 10°, 0° to 20°, 0° to 30°, etc., and the values are readily found by summing up the values in Column 9 "Lumens." For example, the flux between 0° and 10° is recorded opposite 5° and is the same as in Column 9, "Lumens," and the flux between 0° and 20° is the sum of the flux between 0° and 10° and that between 10° and 20° and is recorded opposite 15°. By continuing this process of addition the lower hemispherical flux in lumens will be found and recorded opposite 85° and the total spherical flux in lumens found and recorded opposite 175°. The mean lower hemispherical candle-power and the mean spherical candle-power can then be calculated from the lower hemispherical and spherical flux by dividing them by 2π and by 4π respectively, and the values can then be recorded in this same column in the places provided. The mean upper hemispherical candle-power can then be easily calculated from the mean lower hemispherical and the mean spherical candle-powers, or it can be found by dividing by 2π the difference between the spherical and lower hemispherical flux in lumens. The absorption due to the equipment of the lamp is also to be entered in lumens in this column, but cannot be ascertained until the next column is filled out.

Column 14. Lumen Sums, Lamp Unequipped. The intention is to record in this column the "Lumen Sums" for the lamp without its equipment of globe, shade, or reflector, the values being taken from the thirteenth column of a supposed similar sheet already made out for the unequipped lamp. The mean lower and upper hemispherical candle-powers and the mean spherical candle-powers for the unequipped lamp can also be entered in this column, and from this column also the absorption for the preceding column obviously can be readily ascertained. The absorption for this column, if entered, will, of course, be zero.

Column 15. Per cent. equipped to total flux. In this column are to be entered the ratios in per cent., of the "Lumen

Sums" for the lamp equipped to the total flux in lumens of the lamp unequipped. The absorption in per cent, will also be entered in this column and the values of the mean lower hemispherical, mean upper hemispherical and mean spherical candle-powers of the equipped lamp in per cent. of the mean spherical candle-power of the unequipped lamp.

Column 16. Area of Circle. By "Area of Circle" is meant the area of the circle, in a horizontal plane at unit distance below or above lamp, of which circle the radius is subtended by the angle in the next lower line in the first column. This area is calculated by the formula

$$A = \pi \tan^2 \Phi.$$

Column 17. Average Illumination. The values to be placed in this column are those for the average illumination over the circles, the area values of which are given in the preceding column. These values can be obtained by dividing the flux in lumens received by each circle, by the area of the circle; that is, by dividing the values in Column 13 by those in Column 16; with these values permanently recorded, corresponding values for heights other than unity can be calculated by simply dividing these values in the table by the square of the height in question.

Column 18. Uniformity. In this, the last column, it is intended to place values which will serve to indicate the uniformity of the illumination over the corresponding circle in Column 17, these values being the ratios of the minimum to the maximum values of the horizontal illumination within the circle as obtained from Column 7, "Horizontal Illumination."

BEST ANGLES FOR MEASURING CANDLE-POWER.

It will be observed that, if on the "Angle" sheet there have been recorded the values of the candle-power at 5-15-25 degrees and so on, by steps of ten degrees, there are obtained sufficient data to calculate most of the values provided for, including all the flux, mean candle-power, and average illumination values. If, therefore, the candle-power readings be made at these angles, one can secure most of the values needed without the necessity of making a photometric curve. One large manufacturing and engineering company has already adopted this practice in making tests.

THE "DISTANCE" SHEET.

It is thought that the "Angle" sheets described above will be principally useful for comparing candle-power and flux values for different light sources, but in practical work on lighting problems the columns giving illumination values will not, it is believed, be of so much value as the corresponding columns on the "Distance" sheets. The "Angle" sheet is founded on differences in the value of angle, given in the first column, while the "Distance" sheet is founded on differences in the value of the tangent of the angle, or, what is the same thing, on differences in the distances from the foot of the perpendicular for unit height; for this reason the first two columns are reversed, the values of tan Φ being given in the first column and the values of angle Φ in the second column. The values of Φ are given to the nearest half degree which is close enough for obtaining the proper candle-power values, and they are not intended for any other purpose. The other values on the sheet which depend on the values of Φ are not calculated from the values of Φ given, but from the values of the tangent given in the first column.

It should be noted that the candle-power values from which the flux calculations are to be made, are to be recorded for the angles corresponding to the mid-tangent values instead of for the mid-angle values of the zone. The difference, however, is too small to effect the results. It is likely to be the greatest where the zones are the largest, namely, for the zones near the perpendicular which are about 5½ degrees, and for these zones the error is of the least consequence, as the value of the flux is very small. Taking, for example, the zone determined by the angles whose tangents are 0.0 and 0.1 the angle at which the candle-power is to be read is 3°, while the correct mid-zone angle is 2°, 51′. The candle-power on the sheet for the zone determined by the angles having tangents 0.1 and 0.2 is to be read at 8°, 30′ while the correct value is 8°, 31′.

CRITICAL ANGLE.

At the bottom of the "angle" sheet is a space for inserting the "critical angle" of the light source and this term needs to be explained.

LAMP ....
EQUIPMENT ....
DATA FROM ....
CALCULATED BY .... HEIGHT OF LAMP—*UNITY* .... DATE ....

TAN Φ or DISTANCE from PERPENDICU'R	ANGLE Φ APPROXIMATE	CANDLE POWER	COS² Φ	NORMAL ILLUMINATION	COS³ Φ	HORIZONTAL ILLUMINATION	LUMEN CONSTANT	LUMENS	AREA OF RING	AVERAGE ILLUMINATION	UNIFORMITY	LUMEN SUMS	LUMEN SUMS, LAMP UNEQUIPPED	PER C'T. EQUIPPED TO TOTAL FLUX	AREA OF CIRCLE	AVERAGE ILLUMINATION	UNIFORMITY
.00	0		1.000		.000												
.05	3		.998		.996		.0312		.0314						.0314		
.10	5.5		.990		.985												
.15	8.5		.978		.967		.0909		.0943						.126		
.20	11.5		.962		.943												
.25	14		.941		.913		.143		.157						.283		
.30	16.5		.918		.879												
.35	19.5		.891		.841		.184		.220						.503		
.40	22		.861		.800												
.45	24		.832		.758		.214		.282						.785		
.50	26.5		.801		.716												
.55	29		.767		.673		.232		.346						1.13		
.60	31		.734		.631												
.7	35		.671		.550		.481		.880						2.01		
.8	38.5		.610		.476												
.9	42		.552		.411		.463		1.13						3.14		
1.0	45		.500		.354												
1.1	47.5		.453		.304		.421		1.38						4.52		
1.2	50		.411		.262												
1.3	52.5		.371		.227		.370		1.63						6.16		
1.4	54.5		.338		.196												
1.5	56.5		.307		.171		.322		1.88						8.04		
1.6	58		.281		.149												
1.7	59.5		.258		.130		.279		2.14						10.2		
1.8	61		.235		.115												
1.9	62.5		.218		.101		.241		2.39						12.6		
2.0	63.5		.199		.0894												
2.1	64.5		.186		.0795		.210		2.64						15.2		
2.2	65.5		.172		.0709												
2.3	66.5		.159		.0634		.183		2.89						18.1		
2.4	67.5		.148		.0569												
2.5	68		.138		.0512		.161		3.14						21.2		
2.6	69		.129		.0463												
2.7	69.5		.121		.0419		.142		3.39						24.6		
2.8	70.5		.113		.0380												
2.9	71		.106		.0346		.126		3.64						28.3		
3.0	71.5		.100		.0316												
3.1	72		.0942		.0289		.113		3.90						32.2		
3.2	72.5		.0890		.0265												
3.3	73		.0841		.0244		.101		4.15						36.3		
3.4	73.5		.0796		.0225												
3.5	74		.0755		.0207		.0913		4.40						40.7		
3.6	74.5		.0716		.0192												
3.7	75		.0680		.0178		.0826		4.65						45.4		
3.8	75.5		.0648		.0165												
3.9	75.5		.0617		.0153		.0751		4.90						50.3		
4.0	76		.0588		.0143												
5.0	78.5		.0385		.00754		.491		62.8						113.		
6.0	80.5		.0270		.00444												

NOTE VALUES IN THE COLUMN OF "LUMEN CONSTANTS" AND IN ALL FOLLOWING COLUMNS ARE PLACED OPPOSITE THE CENTER OF THE ZONE TO WHICH THEY APPLY.

Fig. 2.—"Distance" sheet, blank.

If a point, P, in a horizontal plane is at a fixed horizontal distance from a light source suspended over the plane, it will be found that, unless the photometric curve of the light source is of a very unusual shape, there will be some value of the height of lamp source which will give a maximum value of the illumination at the point P, and further this height and the distance to the point will always bear a definite ratio for any particular light source. This ratio corresponds to a certain angle between the vertical and a line drawn from the lamp to the fixed point, and this angle may well be called the "critical" angle of the light source, since at just this angular distance from the light source the point P will receive the maximum illumination, while if this angle is increased or diminished by decreasing or increasing the height of the light source, the illumination at P will fall.

In those cases where a field is to be illuminated by a single light source hung over its center, generally speaking the illumination will be a minimum at the edge of the field, and it will be necessary to place the light source at such a height that this minimum may be as high as possible. If the critical angle, or the tangent of the critical angle of the light source is known, the correct height can readily be determined by dividing the radius of the field by the tangent of the critical angle. Assume, for example, that a light source is suspended over a field having a diameter of ten feet, and that the critical angle is 45 degrees. In such case, the radius of the field is 5 feet and the tangent of the critical angle is unity; therefore, the horizontal illumination at the edge of the field will be a maximum when the height of light source is 5 feet.

When the horizontal illumination values for unit height on the "angle" sheet have been filled in, for any particular light source, it is not very difficult to ascertain the critical angle, as it is necessary merely to ascertain at what angle the value of the horizontal illumination for unit height, multiplied by the square of the tangent of the angle, is a maximum. The proof of this statement is as follows:

The value of the horizontal illumination corresponding to an angle Φ and any height h is found by dividing the value of the horizontal illumination for unit height, corresponding to the

same angle, by the square of the height in question. Thus, if E equals the horizontal illumination at given height, and e the same at unit height, then

$$E = \frac{e}{h^2}.$$

For a point P at horizontal distance, d, from light source,

$$h = \frac{d}{\tan\ \Phi},$$

and, therefore,

$$E = \frac{e \tan^2 \Phi}{d^2},$$

or when d is unity,

$$E = e \tan^2 \Phi,$$

which proves the proposition.

It is interesting to note that for a source of light having uniform candle-power equal to unity,

$$e = \cos^3 \Phi,$$

and

$$E = \cos^3 \Phi \tan^2 \Phi,$$

and it will be found that E is a maximum when Φ is $54°, 44'$.

SUMMARY.

The above description of the engineering data sheets should be sufficient to make clear the object of each column, but it is desirable to call attention to some of their uses and advantages.

It is thought that these sheets will be of particular advantage to the large lamp and reflector manufacturers, since it will enable them to furnish engineers with much more complete information in regard to their product than is furnished by a photometric curve. The sheets can be worked up in whole or in part as the regular routine duty of employees, and a vast amount of duplication of effort in calculation thus saved to the engineers of the company, as well as to those outside. For example, the practicing engineer who desires information in regard to flux distribution finds this information on one of these sheets furnished by the manufacturer and does not have to calculate it himself from the photometric curve. Again, when estimating il-

LAMP 60 WATT BOWL FROSTED TUNGSTEN LAMP
EQUIPMENT PRISMATIC EXTENSIVE REFLECTOR
DATA FROM E.T.L. CURVE PLATE #3796
CALCULATED BY K.R. HEIGHT OF LAMP—UNITY DATE 10-8-23

ANGLE Φ	TAN Φ or DISTANCE from PERPENDICU'R	CANDLE POWER	$\cos^2 \Phi$	NORMAL ILLUMINATION	$\cos^3 \Phi$	HORIZONTAL ILLUMINATION	LUMEN CONSTANT	LUMENS	AREA OF RING	AVERAGE ILLUMINATION	UNIFORMITY	LUMEN SUMS	LUMEN SUMS LAMP UNEQUIPPED	PER C'T. EQUIPPED TO TOTAL FLUX	AREA OF CIRCLE	AVERAGE ILLUMINATION	UNIFORMITY
0	0.0	47.2	1.000	47.2	1.000	47.2											
5	.0875	47.4	.992	47.0	.989	46.9	.0955	4.50	.0977	46.1	97.5	4.5	1.2	.908	.0977	46.1	97.5
10	.176	48.2	.970	46.8	.955	46.0											
15	.268	49.5	.933	46.2	.901	44.6	.283	14.0	.319	43.9	93.5	18.5	5.5	3.72	.416	44.5	91.0
20	.364	51.7	.883	45.6	.830	43.0											
25	.466	55.5	.821	45.5	.744	41.3	.463	24.7	.631	39.2	92.6	43.2	13.8	8.69	1.05	41.1	84.4
30	.577	61.2	.750	45.9	.650	39.8											
35	.700	67.5	.671	45.3	.550	37.1	.628	48.4	1.17	36.2	81.4	85.6	28.9	17.2	2.21	38.7	68.6
40	.839	72.0	.587	42.2	.450	32.4											
45	1.00	73.8	.500	36.9	.354	26.1	.774	57.1	2.25	25.4	56.5	142.7	51.2	28.6	4.46	32.0	38.8
50	1.19	69.0	.413	28.5	.266	18.3											
55	1.43	61.0	.329	20.1	.189	11.5	.897	54.7	4.96	11.0	37.3	197.4	83.5	39.7	9.43	20.9	14.4
60	1.73	54.6	.250	13.6	.125	6.83											
65	2.14	47.4	.179	8.49	.0755	3.58	.993	47.1	14.3	3.29	24.7	244.5	125.2	49.2	23.7	10.3	3.56
70	2.75	42.0	.117	4.92	.0400	1.68											
75	3.73	38.7	.0670	2.59	.0173	.669	1.058	40.9	77.3	.530	11.2	285.4	176.2	57.3	101	2.83	0.40
80	5.67	36.0	.0302	1.09	.00524	.189											
85	11.4	34.0	.00760	0.26	.000766	.036	1.091	37.1	∞	.000	00.0	322.5	229.7	64.8	∞	0.00	0.00
90	∞	322	0.000	0.00	0.000	.000											
95	11.4	31.5	.00760		.000766		1.091	34.4	∞			356.9	285.3	71.6			
100	5.67	30.5	.0302		.00524												
105	3.73	29.2	.0670		.0173		1.058	30.9	77.3			387.8	340.1	77.8	101		
110	2.75	26.4	.117		.0400												
115	2.14	24.0	.179		.0755		.993	23.8	14.3			411.6	389.7	82.7	23.7		
120	1.73	21.0	.250		.125												
125	1.43	19.0	.329		.189		.897	17.0	4.96			428.6	431.0	86.1	9.43		
130	1.19	16.0	.413		.266												
135	1.00	14.4	.500		.354		.774	11.1	2.25			439.7	462.3	88.4	4.46		
140	.839	12.0	.587		.450												
145	.700	9.0	.671		.550		628	5.7	1.17			445.4	483.6	89.4	2.21		
150	.577	6.8	.750		.650												
155	.466	4.0	.821		.744		.463	1.9	.631			447.6	493.8	90.0	1.05		
160	.364	3.4	.883		.830												
165	.268	2.7	.933		.901		.283	.76	.319			448.1	497.2	90.1	416		
170	.176	2.6	.970		.955												
175	.0875	2.5	.992		.989		.0955	.24	.0977			448.3	497.8	90.2	.0977		
180	0.0	2.1	1.000		1.000												

CRITICAL ANGLE	ABSORPTION	9.95 %
	MEAN LOWER HEMISPHERICAL CP	51.4
	MEAN UPPER " CP	20.0
	MEAN SPHERICAL CP	35.7

NOTE VALUES IN THE COLUMN OF "LUMEN CONSTANTS" AND IN ALL FOLLOWING COLUMNS ARE PLACED OPPOSITE THE CENTER OF THE TEN DEGREE ZONE TO WHICH THEY APPLY.

FOR ANGLES BEYOND NINETY DEGREES THE PLANE OF ILLUMINATION IS ASSUMED TO BE ABOVE THE LIGHT UNIT.

Fig. 3.—"Angle" sheet, filled out.

LAMP *60 WATT BOWL FROSTED TUNGSTEN LAMP*

EQUIPMENT *PRISMATIC EXTENSIVE REFLECTOR*

DATA FROM *E.T.L. CURVE PLATE #3796*

CALCULATED BY *I.H.L.* HEIGHT OF LAMP—UNITY DATE *10-8-23*

TAN Φ or DISTANCE from PERPENDICU'R	ANGLE Φ APPROXIMATE	CANDLE POWER	COS² Φ	NORMAL ILLUMINATION	COS³ Φ	HORIZONTAL ILLUMINATION	LUMEN CONSTANT	LUMENS	AREA OF RING	AVERAGE ILLUMINATION	UNIFORMITY	LUMEN SUMS	LUMEN SUMS, LAMP UNEQUIPPED	PER C'T. EQUIPPED TO TOTAL FLUX.	AREA OF CIRCLE	AVERAGE ILLUMINATION	UNIFORMITY
.00	0	47.2	1.000	47.2	1.000	47.2											
05	3	47.2	998	47.0	.996	47.0	0312	1.47	.0314	46.8	99.5	1.5		.301	.0314	46.8	99.5
.10	5.5	47.5	990	47.0	.985	46.8											
15	8.5	48.0	978	47.0	.967	46.4	.0909	4.36	.0943	46.3	97.9	5.8		1.17	.126	46.3	97.5
.20	11.5	48.6	.962	46.7	.943	45.8											
.25	14	49.5	941	46.6	.913	45.2	.143	7.09	157	45.1	96.1	12.9		2.59	.283	45.7	93.6
.30	16.5	50.0	918	45.9	879	44.0											
35	19.5	51.5	.891	45.8	.841	43.3	.184	9.50	.220	43.1	95.4	22.4		4.50	.503	44.6	89.4
.40	22	52.5	.861	45.2	.800	42.0											
.45	24	54.0	.832	44.9	.758	40.9	214	11.6	.282	41.2	97.2	34.0		6.83	.785	43.3	87.0
.50	26.5	57.0	.801	45.6	.716	40.8											
.55	29	60.0	767	46.1	.673	40.4	.232	13.9	.346	40.2	96.1	47.9		9.62	1.13	42.4	89.4
.60	31	62.0	.734	45.5	.631	39.2											
.7	35	67.5	.671	45.3	.550	37.2	.481	32.4	.880	36.8	86.7	80.3		16.1	2.01	40.0	72.4
.8	38.5	71.5	.610	43.6	.476	34.0											
.9	42	73.0	.552	40.3	.411	30.0	.463	33.8	1.13	29.9	76.1	114.1		22.9	3.14	36.3	55.1
1.0	45	73.0	.500	36.5	.354	25.9											
1.1	47.5	72.0	.453	32.6	.304	21.9	.421	30.2	1.38	21.9	69.5	144.3		29.0	4.52	31.9	39.3
1.2	50	68.5	.411	28.1	262	18.0											
1.3	52.5	65.0	.371	24.1	.227	14.8	.370	24.0	1.63	14.7	67.8	168.3		33.8	6.16	27.3	26.0
1.4	54.5	62.0	.338	21.0	.196	12.2											
1.5	56.5	59.0	.307	18.1	.171	10.1	.322	18.9	1.88	10.1	69.1	187.2		37.6	8.04	23.3	17.9
1.6	58	56.5	.281	15.9	149	8.43											
1.7	59.5	55.0	.258	14.2	.130	7.16	279	15.3	2.14	7.15	72.4	202.5		40.7	10.2	19.8	13.0
1.8	61	53.0	235	12.4	.115	6.10											
1.9	62.5	50.0	.218	10.9	.101	5.05	.241	12.1	2.39	5.07	71.8	214.6		43.2	12.6	17.0	9.36
2.0	63.5	49.0	.199	9.76	.0894	4.38											
2.1	64.5	48.0	.186	8.93	0795	3.82	.210	10.1	2.64	3.82	75.3	224.7		45.1	15.2	14.8	7.02
2.2	65.5	46.6	.172	8.02	0709	3.30											
2.3	66.5	45.5	.159	7.24	.0634	2.88	.183	8.33	2.89	2.88	76.7	233.1		46.8	18.1	12.9	5.32
2.4	67.5	44.5	.148	6.59	.0569	2.53											
2.5	68	44.0	138	6.07	0512	2.25	.161	7.10	3.14	2.26	79.1	240.2		48.4	21.2	11.3	4.26
2.6	69	43.0	.129	5.55	.0463	2.00											
2.7	69.5	42.5	121	5.15	0419	1.78	.142	6.04	3.39	1.78	79.5	246.2		49.5	24.6	10.0	3.38
2.8	70.5	42.0	113	4.75	.0380	1.59											
2.9	71		.106		0346		.126		3.64						28.3		
3.0	71.5		.100		.0316												
3.1	72		0942		.0289		.113		3.90						32.2		
3.2	72.5		.0890		.0265												
3.3	73		.0841		.0244		.101		4.15						36.3		
3.4	73.5		.0796		.0225												
3.5	74		.0755		.0207		.0913		4.40						40.7		
3.6	74.5		.0716		.0192												
3.7	75		0680		.0178		.0826		4.65						45.4		
3.8	75.5		.0648		0165												
3.9	75.5		.0617		.0153		.0751		4.90						50.3		
4.0	76		0588		.0143												
5.0	78.5		.0385		.00754		491		62.8						113.		
6.0	80.5		.0270		.00444												

NOTE VALUES IN THE COLUMN OF "LUMEN CONSTANTS" AND IN ALL FOLLOWING COLUMNS ARE PLACED OPPOSITE THE CENTER OF THE ZONE TO WHICH THEY APPLY.

Fig. 4.—"Distance" sheet, filled out.

lumination values in actual work, he need merely to divide the values on the sheet for unit height by the square of the actual height, a process exceedingly simple as compared with what would ordinarily have to be done, and then if intermediate values are desired, they can be obtained by interpolation or by platting an illumination curve. The "Distance" sheet when completed, it is believed will do away with the necessity in much practical work of making an illumination curve. In most cases, any desired values of illumination at distances not recorded on the sheet can be found with sufficient accuracy by interpolation, and for any height by dividing by its square.

Some of the particularly desirable features of the sheets are the following:—

First:—They can be readily filled out piecemeal at convenient times, the work being taken up exactly where left off because all work previously done is permanently recorded.

Second:—Since the sheets contain all the necessary constants they can be filled out without reference to tables or books of any kind.

Third:—At any stage of the proceedings, additional copies of the data and calculations can be obtained by the simple process of blue printing.

It should also be noted that these sheets can be used to great advantage in calculations to ascertain what are ideal photometric curves for particular purposes. If definite flux or illumination values are required, the corresponding candle-power values can readily be determined by working the sheets backwards.

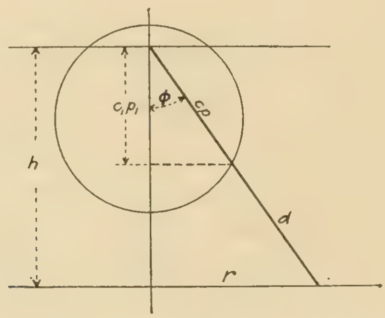
In Figs. 3 and 4 are shown two sheets filled out with data relating to a 60-watt bowl-frosted tungsten lamp equipped with a prismatic reflector of standard design giving "extensive" candle-power distribution.

DISCUSSION.

Mr. V. R. Lansingh:—While I do not wish to discuss Mr. Codman's paper directly, I want to call attention to one simple derivation worked out by Mr. A. A. Wohlauer, which I think has been overlooked. Very often such sheets as Mr. Codman's are not available, but there is at hand only an ordinary photometric curve, from which to calculate the horizontal illumination.

This in the ordinary practice to-day involves a table of cosines squared or cosines cubed. Mr. Wohlauer has shown a method of getting around this table, which I want to call to your attention.

The ordinary formula for expressing horizontal illumination is $I_H = \frac{\text{c-p.}}{d^2} \cos \phi$, where I_H = horizontal illumination, c-p. is the candle-power in the desired direction, ϕ is the angle between



Candle-power and distance relations.

the vertical and the ray and d the distance from the radiator to the point measured. Now c-p. $\cos \phi = c_1\text{-}p_1$., as shown on the diagram $\therefore\ I_H = \frac{c_1\text{-p.}}{d^2} = \frac{c_1\text{-}p_1.}{h^2 + r^2}$, where h is the height of the radiator above the plane of reference and r is the distance from the foot of perpendicular. These two formula avoid any tables and involves only directly measurable quantities.

SOME NEGLECTED CONSIDERATIONS PERTAINING TO STREET ILLUMINATION.[1]

BY PRESTON S. MILLAR.

In a paper presented before the October meeting of the New York Section, the writer called attention to the fact that vehicles, pedestrians and other large objects in the street at night are seen most usually as dark silhouettes against lighted background. This is not always the case, for objects are seen by the aid of light impinging upon them when the light reflected from them to the observer is sufficient to make apparent contrasts on their surfaces or to render them brighter than the background. As, however, most objects seen in the streets are of lower light reflecting power than the street surface and as through the greater part of the length of a street they receive less light than does some portion of the background against which they are contrasted, it follows that they are perceived most usually as dark objects against a lighted background.

Fig 1 illustrates the above point. To quote from the paper just referred to—"The automobile shown was 300 ft. from the camera and nearly 200 ft. from the intermediate lamp. If one had to rely upon the light falling upon the automobile discernment would be out of the question, but the relatively bright street surface which serves as a background makes it easily visible even with the small flux of light here available.

In the photograph one detects the presence of an object because portions of the brightly lighted street surface and trees are obscured. The outline of the obscuring object is recognized as that of an automobile. The presence of the automobile is apparent not because one sees it but because one fails to see the lighted background, within the outline of the object. The phenomenon is simply an eclipse."

This kind of discernment is so obvious and is so generally practiced that it seems almost presumptuous to call attention to it. But the fact is that the literature of street lighting, so far as

[1] A paper presented at the Fourth Annual Convention of the Illuminating Enginee ing Society, Baltimore, October 24 and 25, 1910.

the writer is informed, makes no mention of it, and upon inquiry it is learned that only one of perhaps twenty-five men who are either actively engaged in lighting streets or who have interested themselves in the subject, has recognized this process of discernment. Furthermore, there are certain logical considerations which must be taken into account when this method of discernment is recognized, and these considerations have not been advanced by those who have discussed questions of street il-

Fig. 1.—View showing contrasted-against-light-background method of discernment, non-uniform illumination and glare.
(Taken for the author by the photographic department of the New York Edison Company.)

lumination. In consequence of this it has been considered justifiable to present this "contrasted against lighted background" method of discernment as practically unrecognized. It adds a new viewpoint from which to consider many phases of the subject.

In the course of tests of street lighting conducted for the Lamp Committee of the Association of Edison Illuminating Companies, the writer has been privileged to study the subject

from this and other viewpoints, and begs to offer in this paper some considerations which are supplementary to those to be found in discussions previously available.

EFFECTIVE BRIGHTNESS OF STREET SURFACE.

In order to promote discernment of objects silhouetted against a lighted background, the background, which is usually the street surface, must be made bright. Brightness of surface is subject to so many variables that no unqualified statement can be made as to its value. In this connection one must deal with the apparent brightness when observed at a given angle and from a given direction, as in driving. Such a value for the present

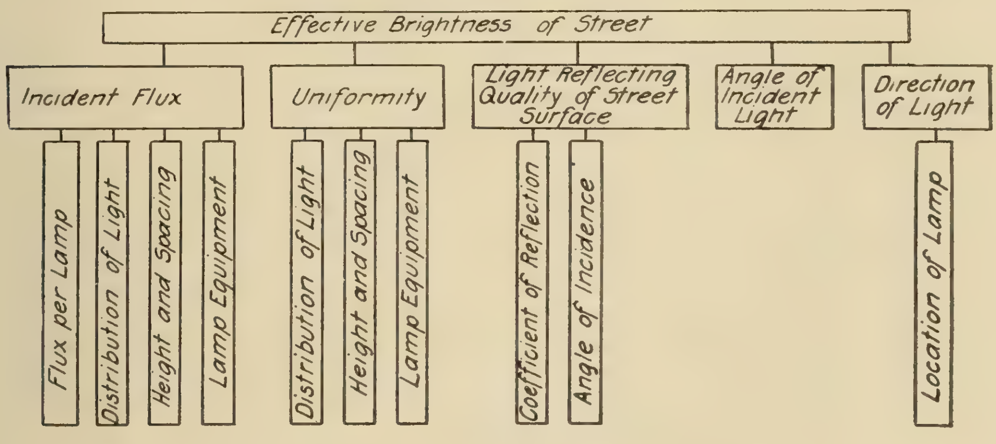


Fig. 2.—Elements determining effective brightness.

purpose may be termed the *"effective brightness."* The effective brightness of a street depends upon the total flux of light which impinges upon its surface, the uniformity of the illumination, the light reflecting qualities of the surface, the angle of the incident light and the direction of the incident light with relation to the direction of view. This is expressed diagrammatically in Fig 2, which shows also the principal variables which enter into each of these elements.

In the following paragraphs will be found a discussion of those phases of the question concerning which the new viewpoint suggests considerations which have been neglected.

DISTRIBUTION OF LIGHT.

Effective and economical street illumination is in large part a

problem of light distribution. Unhappily there is no light source whose distribution is well adapted to street lighting purposes. The unsuitability of all is so obvious that it seems strange that so few really determined efforts have been made to distribute the light from street lamps effectively.

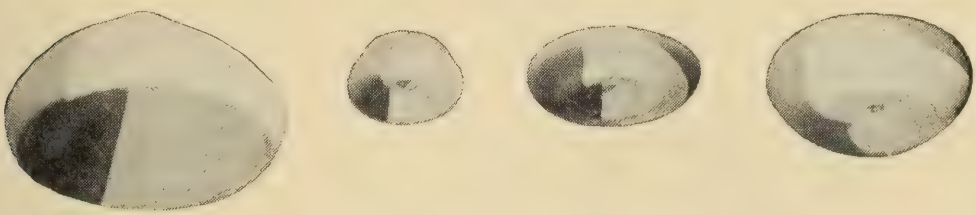
The difficulties arise, first, from the fact that naturally all street lamps distribute considerable light above the horizontal, and, second, all street lamps have a more or less symmetrical distribution about the vertical.

Practically all efforts which have been expended in the improvement of distribution characteristics of street lamps have found application in a symmetrical reflector calculated to direct below the horizontal some of the light which otherwise would be distributed above the horizontal. Such efforts have been successful in varying degrees, most notably in the clear globe magnetite and metallic flame lamps, where a small reflector has been incorporated in the lamp, close and in definite relation to the arc. This has increased the proportion of light directed below the horizontal, but has not affected the symmetry of the horizontal distribution about the lamp. The objection to a symmetrical distribution is illustrated by the fact that if one locates an arc lamp in the street expecting it to do the lighting for a distance of 250 ft. in either direction, the light within the zone utilized is distributed over a circular area of which an 80 ft. street forms only 20 per cent. It is only when lamps are located at street intersections that a reasonably large proportion of the light is applied to the street surface.

The conventional light distribution curve, plotted upon polar coordinate paper, with corresponding curves of illumination intensity computed from the light distribution in a single vertical plane, have tended to direct attention away from this important consideration. Such light distribution curves may indicate a most favorable distribution with regard to considerations of uniformity along the center of a street, but in order to do so there must be a generous distribution of light in the zone immediately below the horizontal. It requires only a moment's thought to see that as a lamp of symmetrical horizontal distribution in-

creases its distribution in the angles just below the horizontal, it also increases greatly the proportion of light thrown upon buildings, trees, and upon lots along the sides of the streets.

In order to present a correct representation of the distribution characteristics of some of the more common forms of street lamps, the writer has had prepared solids whose radii in all directions represent the intensities of light. Some of these are illustrated in Fig. 3. The horizontal ring about each (not shown in the cut) lies in the horizontal plane which cuts the center of the light source. The area which is painted white indicates the light which is directed toward a street 70 ft. wide, when the lamp is mounted 20 ft. high over a point 10 ft. inside of one building line. The light directed elsewhere is either lost or goes toward the illumination of building fronts, in which case a very



9.6-amp. open arc clear globe — *6.6-amp. enclosed arc opal globe* — *4-amp. magnetite clear globe* — *6.6-amp. magnetite clear globe*

Fig. 3.—Light distribution models.—Outline of white surface includes all light which falls upon the street.

small proportion may be reflected to the street. That which is effective in illuminating building fronts is in general not nearly so useful as it would be if directed toward the street. In many places as in residence districts, it is objectionable.

Fig. 4 shows proportions of light from various lamps applied to street surfaces of various widths when the lamps are mounted 20 ft. above one edge of the surface considered. It is shown, for example, that with a hypothetical light source whose distribution is uniformly unity, the percentage of light applied directly to a street of which the sidewalk on one side of the lamp is 15 ft. wide and the street and sidewalk on the other side of the lamp is 55 ft. will be $\frac{20 + 39}{2} = 29.5$ per cent. of the light produced by the lamp.

The corresponding proportions for other lamps would be about as follows:

Lamp.	Per cent. light applied 70 ft. st.[1]
9.6-ampere open arc	46
4.0-ampere magnetite, clear globe	44
6.6-ampere magnetite, opal globe	40
6.6-ampere enclosed arc, opal inner globe	35

The carbon lamps here considered do not derive assistance from reflectors. The open arc directs a relatively large proportion of its light upon the street surface because the light is largely

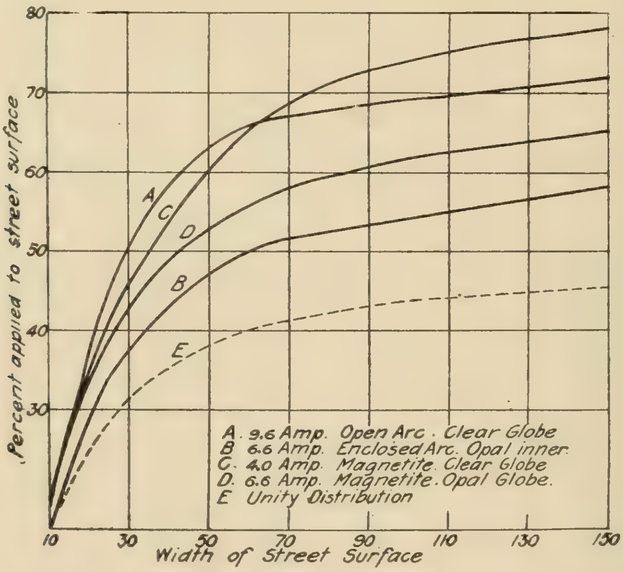


Fig. 4.—Curves showing proportion of light delivered upon surface of street.

concentrated over a small area close to the lamp. The clear globe magnetite ranks high in the list only because the light which it naturally distributes above the horizontal is directed downward by a reflector. The enclosed arc lamp distributes too much of its light above the horizontal to stand well up in such a list as that discussed.

Fig. 5 shows the variations in the proportion of light applied to the street when arc lamps are mounted at various heights. The clear globe magnetite lamp for example, distributes about 20 per cent. less light upon an 80 ft. street when mounted 30 ft. high, than it does when mounted 20 ft. high.

[1] Thanks are due Mr. W. W. Crawford for assistance in procuring these data

It will be noted in these diagrams that as the street becomes wide or the mounting height is decreased the curve for the magnetite lamp increases more rapidly than do the curves for the other lamps. This is an obvious consequence of the relatively high intensity of the distribution from the magnetite lamp in the zone just below the horizontal.

The small proportions of light directly utilized in all cases discussed is a significant demonstration of the ineffectiveness of commercial forms of light distribution, and suggests forcefully the need for more attention to this phase of the question.

As noted earlier in the discussion, one of the fundamental diffi-

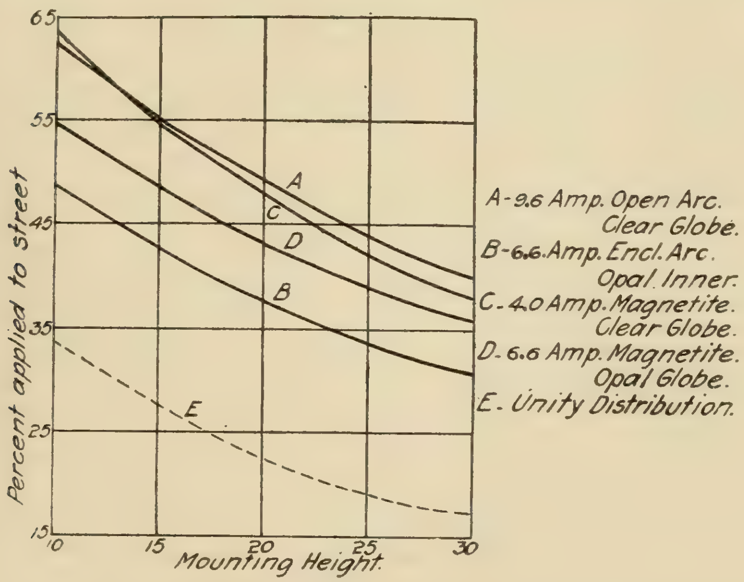


Fig. 5.—Proportion of light delivered upon street with various mounting heights.

culties encountered in utilizing commercial illuminants for street lighting arises from a symmetrical distribution of light about the vertical, a characteristic which is suitable for the effective illumination of circular spaces but not for the effective illumination of long, narrow spaces, such as streets. In the past few years there has been some evidence of effort to redirect part of the light from street lamps, in order to apply it more largely to the street. Some two years ago, a reflector for incandescent lamps was produced which was designed to distribute along the street, some of the light which ordinarily would be directed toward building fronts alongside the streets. Efforts also have

been made to direct toward the street surface, light which lamps naturally direct above the horizontal and upon building fronts.[1]

To illustrate the large gain in effectiveness which may be obtained in this way, a model has been made of the distribution of light about one form of the second reflector just mentioned. This is illustrated in Fig. 6. Comparison with the models of light distribution about arc lamps as shown in Fig. 3 will indicate at once the value of an asymmetrical distribution when made suitable for street illumination. Very little light is emitted above the horizontal this flux being redirected by the reflector. There is little transverse light, the reflector redirecting such rays up and down the street.

To what extent it is desirable to restrict the light from street lamps to the street surface is a question the answer to which depends upon local conditions. It may be said, however, that in

Fig. 6.—Representation of light distribution about tungsten series lamp and reflector designed to deliver most of the light upon the street surface.

general it is practicable to do much more in this direction than has been attempted without bringing about effects which are otherwise objectionable. Quite aside from consideration of the merits or demerits of certain reflectors which are designed to distribute the greatest proportion of the light toward the street surface, this is presented as a suggestive illustration of practicable attainment in this direction.

UNIFORMITY.

Theoretical considerations aside, one must deal to-day not with the question, "uniformity versus non-uniformity" of illumination, but with a choice between various degrees of non-uniformity. Usually this resolves itself into a question of large units widely spaced, as carbon and magnetite arc lamps against tungsten or gas mantle lamps more closely spaced. The ob-

[1] *Transactions*. Ill. Eng. Soc., May 1910.

jection to lighting by larger units is well illustrated by the photograph in Fig. 1. This pictures an asphalt street illuminated by multiple enclosed carbon arc lamps with opal inner globes. The alternate light and dark spaces afford a marked contrast which is not at all pleasing, and there can be no gainsaying the relative difficulty in perceiving irregularities in the street surface in the dark areas between lamps.

Lighting by open arc lamps, spaced, say, 400 ft. apart, is a well-known type of non-uniformity. In such lighting there is a shadow immediately beneath the lamp, surrounded by a ring of relatively high intensity, beyond which the illumination falls off very rapidly. Such lighting has been roundly condemned, always because of difficulty in discernment at a distance of 100 to 200 ft. from the lamp, and sometimes because of the ring of bright illumination which, some claim, renders discernment in the area beyond the lamp more difficult. Such non-uniformity is the direct consequence of the unsuitability of the natural distribution about the lamp.

To remark that the light which reaches the eye and not the light which falls on the observed object is the important factor in illumination, is to utter a platitude. Nevertheless it is necessary to reiterate this statement in this connection. One must differentiate between incident light and the brightness of surface illuminated, not only as a matter of discussion and theory, but as a practical element of the problem.

Curves of illumination intensity have been the basis of most discussion on the subject of uniformity. With respect to this phase of the subject, such curves are likely to be about as misleading as they have proven to be with respect to distribution of light. As a practical matter of seeing in the streets, conditions are rarely so bad as the curves represent. In the first place, one must recognize that sensation of light changes very slowly with changing intensity. In the second place, at points between lamps where the incident light is feeble, one discerns large objects silhouetted against a more brightly lighted background, and in the third place, the increased total reflection and the more largely specular reflection which follows a decrease in the angle of incidence of light upon a surface, very markedly

alters the effect from that indicated by the usual curve of incident light. When dealing with streets variously paved, the sharply inclined rays which fall on the street surface from a point midway between lamps well toward the brighter area of the adjoining lamp are reflected much more generally in the direction of the approaching observer than are the less sharply inclined rays which fall upon the street in greater intensity near the lamp. Briefly stated, the surface midway between lamps appears brighter than the intensity of incident light would lead one to expect.

Under some conditions this effect becomes wonderfully marked.

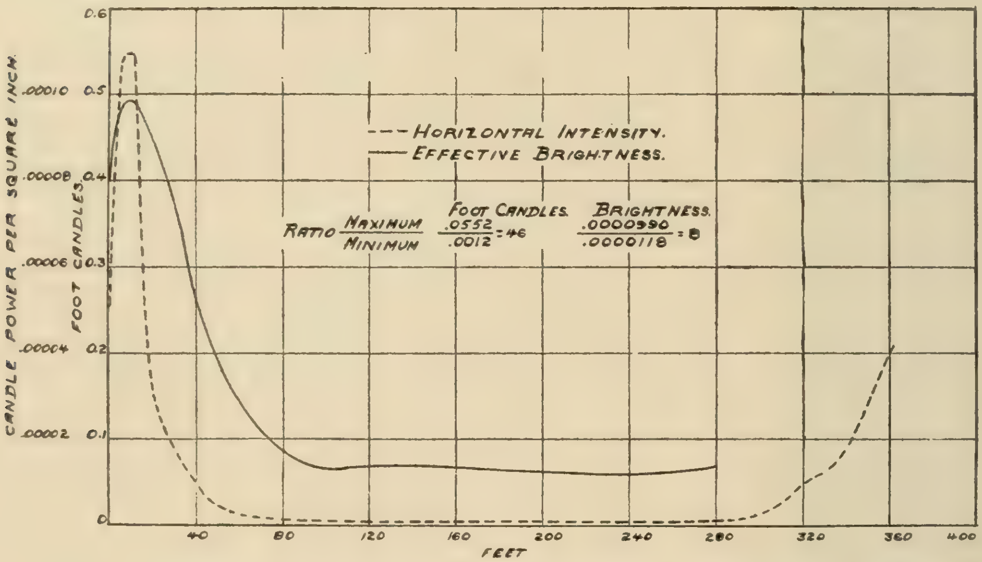


Fig. 7.—Horizontal illumination intensity from enclosed arc lamps spaced 365 feet apart; corresponding curve of effective brightness, street paved with asphalt.

Under other conditions it is small, but in all installations it is an effect which demands consideration and which tends to make the effective brightness of the street more nearly uniform than is the incident light. It is perhaps at a minimum upon a muddy or oiled dirt road. It becomes somewhat larger when the road is dry. It is still larger upon a macadam road. Among city streets, those paved with Belgian block benefit but little from this feature. Asphalt streets benefit in large measure, while some asphalt streets largely traversed by automobiles benefit wonderfully.

Fig. 7 shows values of incident intensity and effective brightness for East Eightieth Street, New York. This is a fairly

typical asphalt street lighted by enclosed arc lamps with opal inner globes. The broken line, indicating intensity of incident light, shows the usual non-uniformity and is more or less indicative of the conditions of street brightness when the street is viewed above, as from the roof of a building. When viewed, however, at a very acute angle as in driving, the variation in brightness of surface is very markedly less and impresses one as being fairly consistent with the inferences to be drawn from

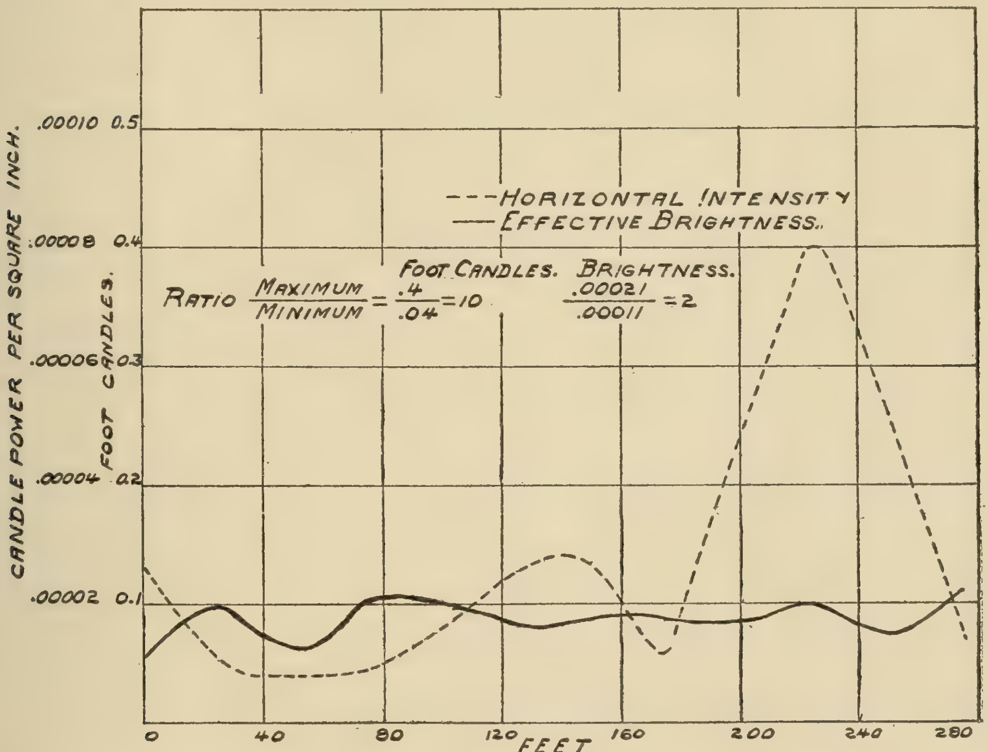


Fig. 8.—Horizontal illumination from arc lamps and corresponding curve of effective brightness. Street paved with asphalt.

the curve of measured brightness as shown by the continuous line curve. The immense difference between the two curves may perhaps best be indicated by the statement that the ratio between the maximum and minimum for the incident light is 46 while for the measured brightness of surface it is only 8.

Fig. 8 shows an extreme state of affairs which is encountered in upper Seventh Avenue, New York City. This street is paved with asphalt block and is largely traversed by automobiles. The street is 130 ft. wide, with narrow parkways along the center. There are two enclosed arc lamps at each street

intersection and one lamp in the parkway in the middle of the block.

It is frequently stated, and it has been the opinion of the writer ever since the installation of the existing lighting system, that upper Seventh Avenue is uniformly lighted, and yet the incident light along either drive varies largely, as is shown by the broken line curve in Fig. 8. The test of effective brightness of street surface shows a high degree of uniformity, confirming impressions of observers. For an explanation of this remarkable state of affairs, one must look to the street pavement. Examination shows that the asphalt blocks which constitute the pavement have become polished as a result of the automobile traffic in all high spots. These small polished areas reflect specularly, while the low spots of the surface which are not so polished, diffuse the light more or less well. In driving through Seventh Avenue, one sees reflected in the numerous small polished areas, images or part images of distant arc lamps. The street is long, straight and lighted by arc lamps arranged in three rows. At a distance, these appear to converge. The consequence is that when looking at the street surface in almost any direction required in driving, one is likely to find some one of the distant arc lamps imaged in one of the small bright areas. These are so generally distributed over the surface of the drive, and notwithstanding the rather wide spacing there are so many arc lamps which may be effective in this way, that the entire drive seems to be very uniformly illuminated.

Now it is to be remembered that a portion of the street surface which receives the most intense light from a nearby arc lamp, will reflect to the eye practically none of this light from the small brightly polished areas which reflect specularly. These appear bright only by reason of lamps located at a distance of one-fourth mile, one-half mile, or even farther away. The portions of the street surface which are not polished will reflect light more or less diffusely, and these are capable of reflecting a considerable proportion of the light toward the approaching driver. They, however, are the little valleys between the polished high spots and in many cases the high spots obstruct light which would be reflected in the direction of the approaching driver. The consequence is that in driving through Seventh

Avenue, when one looks at the street surface 200 ft. or more away, he finds it bright because of the polished surfaces and the distant lamps, while when one looks downward at the nearby surface, he finds it bright by reason of the diffused light when near a lamp and much less bright by reason of the same reflecting process when midway between lamps. In driving and viewing the surface at some considerable distance, it may further be said that in Seventh Avenue the brightness of the surface is almost independent of the nearby lamps. Being dependent on specular reflection from distant lamps, the surface is practically as bright between lamps as it is near a lamp in the zone of higher incident light.

The coefficient of reflection of street surface, as well as the character of reflection, is a factor of great importance. A dirt road after a rain, or an oiled dirt road, is very difficult to illuminate satisfactorily, because it reflects so small a proportion of the light. The ocean beach appears fairly well illuminated even by starlight. With a given lighting installation an asphalt street is brighter than a street paved with Belgian block. Seventh Avenue, New York City, (an extreme case) when compared with another prominent throughfare paved with Belgian block which receives 18 times as much light per square foot, has one-fifth the effective brightness. That is, each lumen on Seventh Avenue, is something like three times as effective as on the other street, an effect due in part to more favorable lamp location, and in part to the better reflecting quality of the asphalt street. Fifth Avenue, New York City, an asphalt street, copiously oiled from automobiles, requires more light for satisfactory illumination than do asphalt side streets which are not traversed so largely by automobiles. In a city where bituminous coal is employed largely, with a given lighting installation and a given pavement, the effective brightness is much lower than elsewhere because of soot on the street surface. Such cities should expend more money on street illumination than do other cities to secure equally satisfactory results.

In general the reflecting qualities of street surface are at least as important in street lighting as are the reflecting qualities of ceiling and walls in interior illumination.

ANGLE OF INCIDENCE AND DIRECTION OF LIGHT.

No street surface approximates the theoretically perfect diffusing surface to which Lambert's Cosine Law may be applied. All reflect specularly more or less, and the specular reflection becomes greater as the angle of incidence becomes smaller. This is a consideration which has a practical bearing upon street lighting problems, in addition to the peculiarities just discussed. Fig. 9 affords an illustration of the kind of reflection encountered in streets. In this case the street was paved with asphalt and the light was derived from a lamp mounted approximately 10 feet above the curb. The surface investigated was about 8 feet from the base of the lamp post. The effective brightness of this

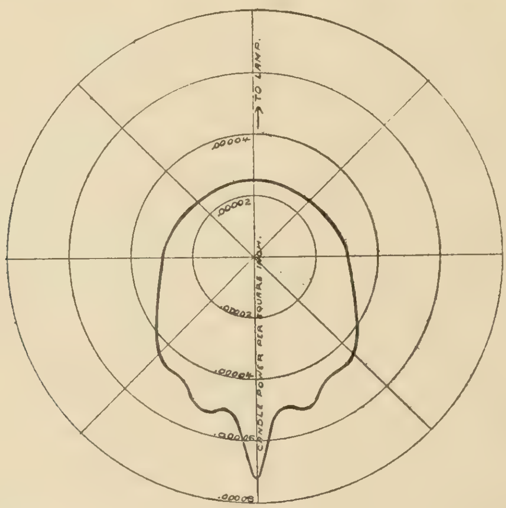


Fig. 9.—Brightness of asphalt when viewed from various directions.

surface when viewed from various directions with respect to the incident light, is indicated in Fig. 9. This shows that in the vertical plane common to the observed surface and the lamp, the reflection in the direction away from the lamp was very much larger than the reflection in any other direction. In this instance the observed surface lay immediately opposite the lamp so that it appeared much brighter when viewed from across the street than when viewed from any other direction.

The mounting height and location of street lamps are directly involved in this connection. As the mounting height is decreased, the average angle of incidence of light upon the street surface is more acute. This means that the reflection in such

cases is more largely specular. It may be said of our street lighting practice that small units are generally mounted low and are generally relied upon to light a length of street which is so short that most of the light falls upon the street surface transversely. To a considerable extent it follows that the reflected light in such cases is directed diagonally across the street and tends to make the surface appear bright to an observer on the sidewalk who looks diagonally across the street. The surface does not appear so bright to a driver whose view of the street is longitudinal. In the usual city installation this effect is very marked. On a fairly wide asphalt pavement illuminated by small lamps mounted low over the curb, it may be noticed at any time, and the effect becomes exaggerated if the street is largely traversed by automobiles and has received a somewhat polished surface. Upon such a street it will be noticed that the street surface near the curb is very bright, due to the fact that there is a strong specular reflection from distant lamps in the direction of the approaching driver. The middle of the street appears very dimly lighted.

Full advantage is taken of the specular reflecting characteristics of street surfaces when lamps are mounted over the middle of a drive-way. In such a street as that last mentioned the surface brightness with a given flux of incident light from lamps mounted over the center of the drive-way is much greater than when illuminated by lamps mounted low over the curb.

This is a consideration which applies more largely in city lighting than in suburban lighting where the specular reflection is not so great, but even in suburban lighting it is a consideration worth remembering.

GLARE.

Under any conditions, an increase in the effective brightness of a street surface promotes discernment of objects on the street, but it is important to remember that it is possible to secure increase in the effective brightness of a street surface at the expense of other conditions of discernment. In any kind of lighting it is well recognized that more light is thrown on an object as the light source is moved nearer the object, but it is also recognized that if the light source is exposed to the ob-

server's view the object may be seen less distinctly when the light source is near it, notwithstanding the greater flux of light incident upon the object. So the subject of glare must not be neglected in a discussion of street lighting when dealing with the effective brightness of the street.

Glare has been talked of more or less in connection with street lighting, for years. Recently it has come to the fore in such discussions[1] and in consequence it seems probable that in the very near future the subject of glare will be more generally investigated than in the past.

The writer has found three effects of glare in street lighting: (1) a measurable decrease in ability to see, due to the presence of a light source in the field of vision; (2) a lessened chance of seeing a barely discernible object when viewed carelessly, even though when a careful examination of the street is made, the object may be discerned just as well in spite of the glare; (3) a condition of transitory glare, due to a temporarily dazzling effect when one looks directly at a light source for a moment and then looks elsewhere and finds it impossible to see well. The last two effects are difficult to measure or even to detect. The first effect may be studied without difficulty.

Some very incomplete data on the first effect of glare is presented in Fig. 10 which shows the results of a laboratory experimental study in which only one light source was used. This study was directed towards the determination of the effect of glare in reducing ability to see. A variable contrast testing device was employed as a test of discernment. An incandescent lamp was placed within the field of vision, being located successively so as to form various visual angles with the test object. The results are expressed in per cent. equivalent intensity, by which is meant the intensity of illumination with which the minimum contrast could be discerned if the glare source were removed from the field of vision.

Curve A shows the decrease in ability to see the contrasted object due to the presence within the field of vision of a 16-c-p.

[1] Symposium by experts conducted by the British Illuminating Engineering Society. See (London) *Illuminating Engineer*, 1910. Discussion notable for differences in opinions expressed

"Analyses of Illumination Requirements," by Arthur J. Sweet, *Journal of the Franklin Institute*, May, 1910. An interesting discussion of the "Light Distribution and Glare Features of Street Lighting" with report of same pioneer experimental work on glare.

clear bulb lamp, located so that the line between the observer and the lamp formed various stated angles with the line between the observer and the contrasted object. The illumination intensity on the test device remained constant at 0.05 foot-candle, and the results are shown in terms of equivalent reduction in illumination intensity. This means that with the glaring source two degrees removed from the contrasted object, the effect on visual power of the observer was the same as that which would follow a reduction of 68 per cent. in the intensity of illumination on the contrast test device. When the glaring source is within one degree of the observed object, discernment is often impossible under low illumination intensities.

Curve B shows similar information, the conditions remaining

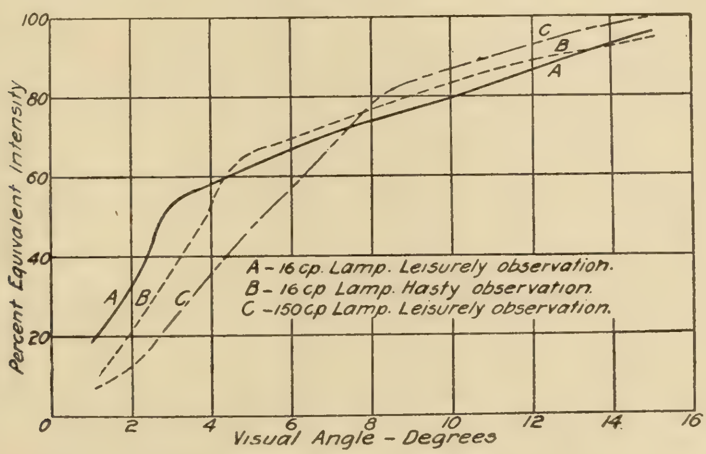


Fig. 10.—Results of laboratory experimental study of glare using only one light source.

the same, except that the time of observation was limited to successive exposures of approximately one second, whereas in obtaining the data given in Curve A, observations were extended over as long a period as desired.

The data shown in Curve C were obtained under conditions similar to those which applied to Curve A, except that the 16-c-p. lamp was replaced with a 150-c-p. clear bulb tungsten lamp. In all cases the observer was stationed 50 feet away from the contrast device and the glare source was moved through an arc 40 feet away from the observer.

The curves indicate that the deleterious effect of glare within 4 degrees is greater when one obtains a quick glimse of an

object than when one has opportunity for leisurely observation. At higher angles the test data indicate a reversal of this difference. Here, however, the difference between the two curves is so slight as to make it seem probable that it is a difference due to experimental inaccuracies rather than one inherent in the conditions.

The effect of the use of a larger glaring source brings, as might be expected, an increase in the harmful effect of the glare. In this case, again, the curve of glare effect crosses the curve obtained when a smaller source is used, but as in the other case, the differences in the test data are very small and may be due to test inaccuracies. The uniform manner in which all of the curves of glare effect approach 100 per cent., which is the equivalent of a condition of no glare, is notable. Whether these curves are asymptotic or actually cross the 100 per cent. line, is to be determined. A few of the writer's experiences in the streets lead him to believe that it is not beyond the realm of possibility that under certain conditions the curves may cross the 100 per cent. line, so that the presence of the glaring source when it is far removed from the observed object, may actually be slightly stimulative rather than harmful. There has not been opportunity to investigate this.

Application of these laboratory data to conditions as found in the streets, is difficult, due to complications which arise as a consequence of the presence of a number of glaring sources within the field of vision, and the more or less intense illumination of surroundings. Practically the only case where one finds in the streets conditions comparable with those which obtained in the laboratory tests reported above, is a location on a curving road where a single lamp is placed alongside the street and no other lamps or lighted areas are visible. Happily such installations are rare. They form such small exceptions that in this general discussion they need not be given much attention.

In our streets, one or more rows of lamps are usually so located that a number of lamps come within the observer's view, spaced angularly from almost the center of the field of vision to near the limit of view. Fig. 11 illustrates the manner in which distant lamps approach closely the center of the field of vision. At a distance of only 800 feet, when lamps are mounted

20 feet over a curb on a 50-foot roadway, the visual angle between the lamp and an object five feet above the center of the street, is only two degrees. Another reference to Fig. 10 will indicate how harmful such lamps are to vision, when it is remembered that lamps at a distance of a half mile appear very nearly as bright as they do at a distance of one-quarter mile.

Tests of glare in the streets as well as general observation have indicated that the distant lamps which are near the center of the field of vision are the lamps which are most harmful from the glare standpoint. Nearby lamps which are not near the center of the field of vision, do relatively little damage. This is in keeping with the indications of the laboratory test data shown in Fig. 10. When the observed object is within one

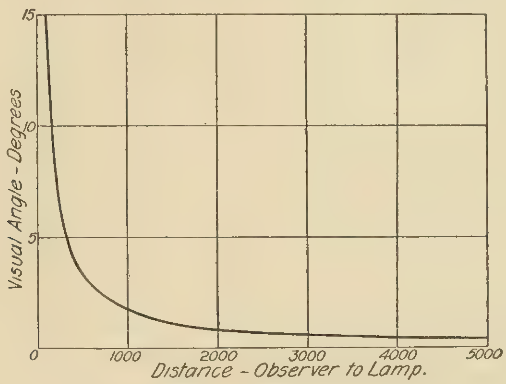


Fig. 11.—Visual angle separating glaring source and observed object in street.

degree or less of a glaring source, such as a distant arc lamp, it usually is not discernible unless in the immediate region of a lamp, so that the intensity of illumination on the object is high. So, for example, in observing an approaching automobile in a thoroughfare like Fifth Avenue, New York, it is a common experience to be able to discern the vehicle readily without being able to see the heads and shoulders of the occupants. The distant arc lamps are absolutely prohibitive to seeing objects which are removed from them by an angle of no more than one degree, but the glare effect falls off so rapidly, and vision is assisted so markedly by the brightly lighted background, that the lower portions of the vehicle may be discerned without difficulty. The same conditions prevail in the lighting of side streets, where arc lamps are located at distances of, say, 250 feet.

It is most fortunate for our ability to discern objects that most such objects are so large that if some portion is rendered invisible by reason of the glare from distant lamps, some other portion may be discerned in almost all cases because it is so far removed angularly from the glaring source that the glare effect is no longer prohibitive to seeing.

The conditions of glare as found in many streets are illustrated with considerable fidelity by the photograph in Fig. 1. The halation area in the photograph reflects to the eye much more light than does any other portion of the photograph. To an extent, this gives a true example of glare. By moving the photograph nearer to one eye, with the other eye closed, the visual angle between the automobile and the glaring lamp may be altered. It will be noted that as the photograph becomes more distant from the eye and the visual angle becomes smaller, the objectionable effect of the glare is more noticeable, but under any condition one can actually see the automobile in the street nearly as well with the glare as without it. In addition to slight reduction in ability to see the automobile there is a very noticeable intrusion of the glaring source, which is very annoying and which distracts attention from the automobile. When the glare is removed, the automobile is easily the most notable object in the picture. It impels vision far less strongly when the glare is unobstructed. If one gazes directly at the glaring lamp for a few minutes, his eyes are slightly dazzled, and in the succeeding moment he can see the automobiles less well.

There are two ways to diminish the effect of glare sufficiently to avoid harmful effects. These are (1) permit no exposed lamps to be located near the center of the field of vision. The writer believes that satisfactory results will be achieved if no lamps can be seen within five degrees of the object viewed; (2) make the effective brightness of the street high. No study of glare in the streets can lead to correct final conclusions unless it takes into account the effect upon an observer's ability to see objects when silhouetted against a lighted background.

CONCLUSIONS.

To recapitulate, it is to be noted that objects in streets

at night are discerned most usually as silhouettes against a lighted background. The first requirement of good street lighting is for a well lighted street surface to serve as a background. It is the effective brightness of street surface, or the brightness as seen when viewing the street longitudinally at an angle of 2 to 3 degrees, which determines the value of the surface as a lighted background. The effective brightness may be increased by providing a greater number of more powerful lamps or by repaving the street with material having more favorable light reflecting qualities. The light distribution characteristics of all commercial illuminants being unsuitable for street lighting, it would appear feasible to increase the effective brightness of streets by directing a larger proportion of the light upon the street surface. With a given intensity of incident light the effective brightness of a street is greatest when the lamps are mounted over the driveway. Non-uniformity of illumination, while undesirable, is not so objectionable as has been asserted, because (1) the effective brightness of street surface does not vary as much as does the intensity of incident light, and (2) the bright street surfaces near lamps assist in discernment of large objects in the dimly lighted regions.

Glare must not be neglected. Its effect becomes harmful when the glaring source is very near (less than 5 degrees removed from) the object to be seen or when there is no lighted background against which to view objects. In ordinary city installations the glare from street lamps may dazzle temporarily after one looks directly at the lamps, and may increase the chance of failure to perceive a barely perceptible object in a hasty, careless glance. But otherwise it occasions no material decrease in ability to see objects. It is entirely feasible to design a lighting installation in which there shall be entire absence of objectionable glare while securing high effective brightness of street surface. But usually in practice one must choose between decreased effective brightness of street on the one hand and some degree of glare on the other. For each such installation there is some compromise which will produce the best results. The proper compromise can be reached best not as a matter of theory or prejudgment, but as a matter of trial in the street, preferably

including a determination of ability to see under the various conditions.

The problem of street illumination is not simple when considered alone as a matter of theory. The additional elements which commercial conditions introduce render it extremely complicated in practice. A number of the factors which enter into the problem might be studied independently with profit. But the application of the results of such studies must always be made with due regard to the importance of other factors. Our tenets of street illumination must be broad-gauged and must give proper weight to all elements of the subject, whether scientific or commercial.

This paper does not purport to be a general discussion of street lighting. It aims to present considerations which have been neglected and which are supplementary to those to be found in the TRANSACTIONS of this Society and elsewhere. If it shall prove successful in drawing attention to the "contrasted-against-lighted-background" point of view regarding street lighting, and in securing consideration for those aspects of the problem which follow logically upon a recognition of this view-point, the purpose of the paper will have been accomplished.

DISCUSSION.

Mr. A. J. Sweet:—I should like to express, first, my very high appreciation of the great value to the subject of street lighting which the paper has. I believe that the considerations which it has brought forth are deserving of very great consideration and that they have received practically no consideration in the past. I think there is nothing of importance in Mr. Millar's paper to which I want to take exception or express a disagreement; nevertheless I feel that the paper has a certain element of danger in it, in emphasizing certain considerations in street lighting. These considerations being new, and ones that deserve special emphasis for that reason, the impression is apt to be conveyed that these considerations are perhaps of larger importance in the complete subject than they really are. I would not be misunderstood in this statement. I believe that all the considerations that the author has brought forth are of very great importance, but I think possibly there is apt to be an inclination to

make them the fundamentals of the subject, whereas there are certain other considerations which I know the author perfectly well recognizes are even more fundamental. I should like very briefly to draw attention to several of these points.

In the first page of the paper is the statement: "Objects are seen by the aid of light impinging upon them when the light reflected from them to the observer is sufficient to make apparent contrasts on their surfaces or to render them brighter than the background." I think the fact of seeing by contrast is a much larger one than might be inferred from a hasty reading of the paper. My observation has led me to believe that we really see largely by contrast; that it is only in those installations which are to be condemned as relics of the past where the seeing by silhouette effect, by eclipse, is predominant. In the installations to which we are rapidly progressing and which commercial conditions make entirely feasible to the progressive engineer of to-day, seeing by contrast on the surface of the object, in other words, distinct features of the object, is entirely practical. I merely call attention then to the fact that seeing by eclipse, which is a very important thing to regard when the money available per running foot is very limited, is of far less importance when there is a more enlightened public opinion which will permit of proper expenditure for energy.

The author speaks about a non-symmetrical distribution relative to street lighting, where the lamps are placed far apart as was the case in all the older street lighting installations. It is obviously very important to get non-symmetrical candle-power distribution if the light flux is to be well placed. I should like to call attention to the fact that when the units are placed more closely together, as is the practice in the most modern ornamental street lighting to-day, the need of non-symmetrical distribution is greatly reduced. Of course, it never entirely vanishes, but it practically would vanish if the lamps were arranged at a distance apart equal to the width of the street and the lamps were hung over the center of the street. As a matter of fact, when the lamps are spaced as is not infrequently the case, eighty feet apart on the same side of the street, and in ornamental post installation, there is not a secondary but a tertiary need of a non-

symmetrical candle-power distribution. It is a comparatively unimportant factor.

The author states: "Theoretical considerations aside, one must deal to-day not with the question of 'uniformity versus non-uniformity' of illumination, but with a choice between various degrees of non-uniformity." I differ with him on that point; it is perhaps the only point where I should like to express myself as strongly differing with him. One of the most spectacular things not only in our own end of the general profession of illuminating engineering, but perhaps in the whole profession of illuminating engineering of the present day, is the tremendous movement toward larger expenditures of wattage for street illumination. The main factor perhaps in bringing this about has been the realization by the merchants of the fact that a higher standard of lighting promotes their business, so that they can afford to pay for it. There are many installations of to-day where ten watts per running foot is expended on electric lighting. Where there is an expenditure of anywhere near ten watts per running foot, I should say expenditures of down to two or three watts per running foot, it is entirely possible for the designing engineer to get just as near to perfect uniformity as is obtained in interior lighting. As a matter of fact, if approximate uniformity, say of four to one is obtained I believe there is sufficiently-close uniformity. If it is important to get uniformity it can be obtained to-day in a great many installations.

The curves shown in Fig. 10 are very interesting indeed. From a certain series of laboratory experiments made to obtain a very similar type of curve, I found minimums very close to the author's. My values at zero visual angle degree and percentage equivalent in intensity were slightly higher than his, but approximately the same. On the other hand, in my experiments I found that the 100 per cent. light was not reached until from 23 to 26 degrees, say 25 degrees as an average value. I am inclined to believe therefore that the slope of the curve is less steep than is shown in Fig. 10, and that the curve is either a straight line or so slightly bending upward that it would approximate a straight line.

I believe the avoidance of glare is the most important factor in street lighting. In this connection I should like to call at-

tention to one fact which the author does not mention in his paper, namely, glare need not necessarily come from the street lamp itself. Where there is any considerable element of reflection there is a glare from the light reflected from the street, and I believe that in the case of a partly wet asphalted street this may be a very objectionable feature of the street illumination. I believe the ideal street surface would be that which acted somewhat as white blotting paper does; the street covered with clean snow is an example of a surface that is fairly diffused in its reflection but has a high coefficient of reflection. I think more importance should be given, however, to the consideration of the character of the street reflecting surfaces.

I believe there will be a development tending towards closer spacings and much smaller units than in the past, the spacings eventually approaching to an ideal of four times the height for the separation between adjacent units. I believe that not only the theoretical considerations warrant rather closer spacings, but there are already afoot certain purely commercial elements today which make them entirely practical.

Mr. R. C. Ware:—I agree with Mr. Sweet entirely, that the important thing is the avoidance of glare. The author's idea of silhouetted objects to be seen against a light background is certainly valuable for long spacing of the units. Such long spacing, however, is a thing that we want to work away from for the reason that near the lamps there will always be a high intensity on the object, so that the silhouette effect near the lamps will not be so marked, while far away there will be a comparatively much lower intensity of normal illumination, so that the silhouette effect will be important. Therefore, there is some intermediate point at which the object on the street is neither silhouetted nor illuminated; in other words, it merges with the background, and that is the danger point. Therefore it seems to me that what there should be a closer spacing of the units, so that one need not rely solely on the silhouetting of objects.

Dr. C. H. Sharp:—The statement has been made that the silhouetting effect is obtained only when the lamps are spaced pretty far apart and the lighting is pretty poor anyway, while where the lighting is really good objects are seen by the light

that falls upon them. Now, that simply is not true as I know through my own observation. I did not notice this fact until after Mr. Millar had called my attention to it, but I know it now. Consider a street that is as well lighted as Fifth Avenue in New York. There are two inclosed arc lamps on each pole, and enough of them to the block to make it an exceptionally well lighted street. In watching the moving vehicles on that street what one actually sees is the vehicle some of the time showing by the light reflected from it, and then a moment later showing as a silhouette against the background. Most of the vehicles are black, and the intensity of illumination that one would have to put upon them to make them visible by themselves and bring out the details, when there aren't any details, would be enormous. As a matter of fact when a vehicle is very near and right under a lamp, some details of it may be distinguished. As that same vehicle moves away a hundred feet or so farther, it is seen as a silhouette against the background. The talk of abolishing the seeing of things by silhouette is absolutely riduculous. The only way one could do it would be to make the street surface blacker than the carriages, and then maybe objects could be seen some of the time, but usually one would not be able to see anything at all.

The statement has been made that the lighting of streets by lamps spaced at considerable distances is out of date and does not amount to anything at all; and that in the future the streets will be lighted by putting lamps every little way along and getting conditions which are practically ideal. Now very fortunately more and more streets will be lighted in that way, but I wish to call attention to the fact that just as soon as the illuminating engineer has placed at his disposal unlimited means, that is to say, an unlimited amount of light to use, the problem of street lighting simply disappears. It is not at all difficult to light a street if an unlimited number of lamps can be put up. It is only when one has to light a street with about one-tenth or one-hundredth of the amount of light that he ought to have that any problem in street illumination is presented. However, this is the practical condition at the present time and it will continue for years to come in the great majority of the streets; that is, in the greatest percentage of mileage of the streets. Along cer-

tain favored highways, certain of the principal business streets, certain ones of the show streets or streets where the night traffic is particularly heavy, very much improved conditions of illumination will exist and the ideal results can be approximated.

The statement has been made that the most important consideration in street lighting is the avoidance of glare. Now that is not in accordance with my idea. My idea is that the most important thing in street lighting is to put light on the street. Without any light on the streets, absence of glare is a thing of negligible importance. Glare is an effect of importance undoubtedly, but it might be classed as one of those things which are subject to the danger of over emphasis. Now what does glare do? To my mind there seems to be two effects. In the first place, if we attempt to see things with a glaring light in our eyes, with the lamps in the line of vision, there is what has been called the halation effect, which is very marked. The halation from a source of light extends to a certain distance around the lamp. One who has ever attempted, for instance, to look at a bright star or planet quite near the full moon, will recollect that around the moon is a halo of light, and it is rather difficult to see the stars inside that halo. That halo has rather distinct limits beyond which the star can be seen quite well if the vision and attention are concentrated upon it. I believe that one effect of glaring lamps is to cause a distraction of attention, so that one does not see things so well if the glare is there, unless he takes an especial care to concentrate his attention upon the thing which is seen. For a certain distance from the glaring lamp the effect of the glare is very marked, but it falls off rather rapidly. Beyond its halation zone, the glare pretty well disappears and the effect of it must decrease rather more slowly. Consequently, the probability of such a curve as the author has presented in Fig. 10, which shows a rapid decrease of glare at first and afterwards a more slow one, seems to be greater than the probability that the glare effect follows a straight line law. However, I believe that this effect requires a great deal more consideration, and I do not think that we should avoid over-emphasizing the effect of glare in the streets. As I have had occasion to say before the New York Section, in efficient street lighting, with lamps spaced well apart,

the question is that of light plus some glare, or no glare and no light.

Mr. S. W. Ashe:—Regarding the acuity curve of Fig. 10, Mr. Sweet's limits checked quite closely with those given. About two years ago I made similar tests at an angle of about 8 degrees. The values obtained were presented before the Illuminating Engineering Society. I think they were the first published values on the effect of a foreign light in the field of vision. I found that the efficiency was decreased by about 30 per cent. This value checks quite closely with the middle portion of Mr. Millar's curve, so that there is a check in the middle as well as at both ends.

Mr. G. H. Stickney:—In regard to the question of glare, etc., my observations agree with those of Dr. Sharp. I believe that there are other features of street illumination of at least equal importance with glare. The importance of glare depends not only on the locations of the glaring lamps, but on the contrast of their backgrounds.

In the principal streets of a city the economic situation permits the use of a high intensity of light and this can best be secured by employing large units located well above the street and with such spacing as to give an approximately even intensity on the street surface. I do not believe, however, that low intensity and wide spacing in street lighting will disappear. When the enormous mileage of streets and roads now totally unlighted is considered, one must realize that with the raising of the standard at the center of the city the less intense class of lighting will extend further and further out into the country and provide the best system which the cost of lighting will make possible.

The lighting of streets by contrast or silhouetting is proving very useful where only low intensities of light can be afforded. This effect was first called to my attention in connection with railway yard lighting, in which were provided directing reflectors to cut off the light from the eyes of the switchman and throw all the illumination in the direction of car movement. I was surprised to find that the switchmen preferred to have the reflectors turned so as to throw the light toward them. On investigation I found that with this arrangement the cars were

seen silhouetted against a lighter background. With the low intensity which was provided this proved much more satisfactory than the other method.

Considerable thought has been given to the asymmetrical distribution of light for street lighting. Previous to the adoption of the radial wave reflector I submitted to Mr. Ryan certain designs of reflectors for concentrating the light in two or four directions. After careful study, however, these designs were rejected because it was thought impracticable to furnish reflectors to meet all conditions of street lighting and because difficulty was likely to be encountered in getting reflectors properly hung so as to throw the light in the proper directions. My later observations seemed to confirm this decision. The radial wave reflector was really developed from this reflector, securing a symmetrical distribution simply by multiplying the number of concave surfaces. In this connection it should also be borne in mind that light thrown outside the roadway is not entirely wasted. While the greatest intensity is required in the roadway, the pedestrians should be considered. Therefore, light on the sidewalks, on the fronts of buildings, lawns, etc., is very desirable.

Mr. H. T. Owens:—The best thing about the paper is that it has caused many of us to talk about street lighting and I hope more of us will think about it. Many of the people who have had charge of new lighting installations throughout the country during the last two or three years have not thought very much about what they were doing, let alone knew very much about it.

I endorse what Dr. Sharp says about silhouette effects, about glare and also about the quantity of light which is available for ordinary street lighting. Regarding uniformity, if the wattage of the system is increased in order to obtain uniformity, the horizontal candle-power distribution must not be neglected. Uniformity may or may not be desirable, but there must be horizontal distribution, since to it is attributable the handsome effect, which is necessary in the street lighting installations where a large quantity of light is used.

Mr. A. J. Marshall:—In street lighting the question of color is about as essential as in interior work. This is true first from the efficiency viewpoint; that is to say, use must be made of a

radiator which will produce a light which will enable one to see after reflection from the different kinds of pigments encountered. It is true, secondly, in so far as the effect of direct light to the eye is concerned. In the case of a street lighted with arc lamps, with milk globes, even in the absence of glare, one's attention is directed to those illuminants. If they could be neutralized, that is to say, if they could be so equipped that there would be no contrast between them and the background, which may be a building or the sky or what not, one's ability to see would be very much enhanced. I would suggest lightly straw tinted globes on enclosed arcs instead of the usual milk type.

As regards the question of glare effect, I think most of the observations have been made with the eye looking at some fixed point; in practice, however, the eye does not remain in a fixed horizontal plane of direction, but is moving. This movement of the eye should be taken into consideration.

Dr. H. E. Ives:—The glare which is most dangerous is that from lamps very nearly in the line of vision. It seems to me that in a great majority of cases lamps that are used primarily for illuminating a street are far enough out of the line of vision so that there is little glare from them. The lamps that do cause trouble are usually the ones in the store windows. There are two classes of store window illumination. One has been designed by an illuminating engineer; he puts the lamps along the top and conceals them. The result is that the objects in the window are beautifully illuminated and attract attention. The other type is designed by a plumber or wireman and consists of a line of bright tungsten filaments squarely in the line of vision at such a height that if one is on the other side of the street and wishes to go across, he looks to see if there is an obstacle in the way, and is immediately blinded by these tungsten filaments. I suggest to the gentlemen who are doing missionary work in the line of illuminating store windows, that the most harmful glare in the streets is that from badly illuminated windows.

Mr. J. G. Felton:—The author says: "In a city where bituminous coal is employed largely, with a given lighting installation and a given pavement, the effective brightness is much lower than elsewhere." I should like to ask him if any values of this kind have been obtained by comparing such cities with cities

where anthracite coal is used? Taking a given installation and a given pavement, what increase in wattage would be required in such a city over a city where anthracite coal is used, to secure equally good results?

Mr. Millar:—I cannot agree with Mr. Sweet that an asymmetrical distribution for street lamps is relatively of little importance, because street lighting is becoming more intensive. It must be important when in streets illuminated by magnetite lamps only 30 to 40 per cent. of the light given by the lamps is directed upon the surface of the street, notwithstanding that none of the light is distributed above the horizontal. Asymmetrical distribution is of course more important where there is only one lamp every five hundred feet, but in any case it is desirable and must remain desirable so long as streets are long and narrow, as they are likely to be for some time to come. Uniform intensity has been achieved, says Mr. Sweet, or can be, wherever it is worth while. Of course it can, but it has been achieved so far practically only by placing a large number of lamps in the street, locating them so closely that the result cannot help but be uniform lighting. This is attained not by efficient and economical design but by extravagant expenditure of energy. In a number of other respects Mr. Sweet differs from me; in most cases, the difference arises because he does not attribute as general prevalence to the silhouetting effect as I do. I think my answer to Mr. Sweet on those matters will be an invitation to take an automobile ride with me the next time he comes to New York.

I have been studying silhouetting effect for six months or so and I believe it is the most common method of seeing things in the street. I am speaking from the standpoint of a driver of a vehicle. Now call to mind the average street surface; how bright is it? If an object is darker than the average street surface it is seen as a silhouette; if it is lighter than the average street surface, it is seen by reversed contrast. The driver of an automobile must see in particular pedestrians and vehicles, and the light reflecting quality of the average vehicle or pedestrian, is less than that of the average city street surface. Therefore, vehicles and pedestrians are seen most usually as silhouettes against the street surface.

Concerning the question of soot I should like to say that it was first called to my attention when I was in Chicago, looking at some lighting experiments on Michigan Boulevard, and I could not understand why the lighting appeared so ineffective. After comparison with similar streets in other cities lit more or less similarly it was borne in upon me that the deposit of soot on the surface of the street is detrimental to the street lighting to a degree which is very difficult to overcome by any lighting means available. It is a very important factor.

Mr. Marshall raised the point of color in street lighting. Undoubtedly it is very important and I hope some day to have a chance to study it.

THE RELATIONS BETWEEN PRESSURE AND LIGHT OUTPUT WITH VARIOUS GAS LAMPS AND BURNERS.[1]

BY NORMAN MACBETH.

One of the most important considerations in gas illumination is the effect of pressure upon the lamps and burners used. In taking up an investigation of this subject it was found that there are two types, the open flame and the incandescent mantle burner to consider, each of which gives the better results under somewhat different pressure conditions.

Early work on this subject, with low pressure only, has been devoted almost entirely to pressure up to one inch of water, and not in any instance that the writer could find have investigations been reported beyond three inches. The entire subject is one capable of many opinions; considering, however, the enormous increase in light production possible with the incandescent mantle lamps it is hardly conceivable that the open flame requirements, that is the pressure conditions most satisfactory for the use of open flames, should govern and practically force the specifications for the pressure at which the gas shall be supplied. Unwise legislative enactment and a general failure by those who should be most interested to appreciate properly the conditions must be largely responsible for the present situation.

In 1904 C. R. Boys reported[2] that in Germany 94 per cent. of the lighting by gas was done with the mantle burner. More recent statements on the conditions at this time bring this amount up to 98 per cent. Boys also reported that as a result of an enquiry in 1903 in a large town in England, only 23 per cent. of the gas used for illuminating purposes was for incandescent lighting.

In Canada two-thirds of the gas used for illumination is with incandescent mantle lamps.[3] Estimates have been given at various times for the United States, but not in any instance noted

[1] A paper presented at the Fourth Annual Convention of the Illuminating Engineering Society, Baltimore, October 24 and 25, 1910.

[2] Report of the Departmental Committee as to Gas Testing in the Metropolis-(London) 1904.

[3] Report of Committee on Candle-power and Calorific Value, Canadian Gas Assn., 1910.

has the proportion of incandescent mantle lamps exceeded 15 per cent. of the gas outlets installed.

There are many that agree that the illuminating quality of ordinary artificial gas varies with the quality of the gas and kind of burner used, although in what proportion does not seem to be as definitely settled. Large variations are due to the mechanical apparatus employed for developing the light, a statement which cannot possibly be opposed but which nevertheless has been frequently overlooked. This fact has been set out by W. J. Didbin[1], "Not to take into account the influence of the burner when testing the illuminating power of gas is as great an oversight as if, when weighing, one were to make no examination of the balances; or if an engineer were to take no account of

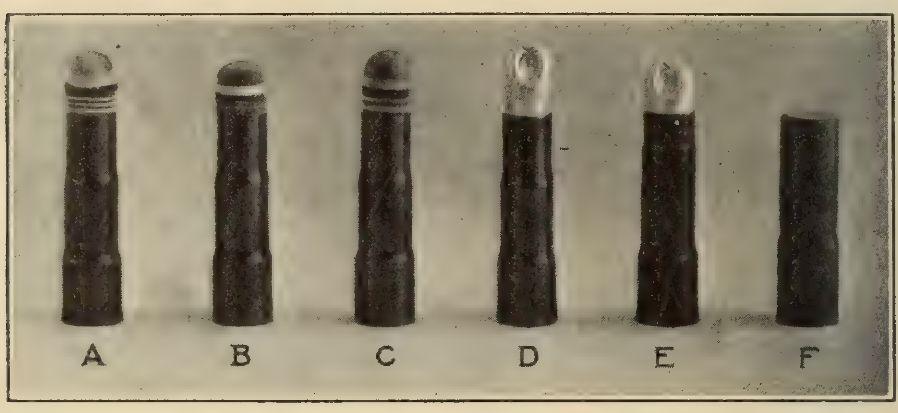


Fig. 1.—Open flame burners.

the boilers he employed, and then, finding that a ton of coal in some circumstances created a greater portion of steam than when half a ton was used, would have jumped to the conclusion that the heat-giving power of coal became greater, relatively to the quantity consumed, when a ton was used than when half that quantity was employed. What a boiler is to coal and generation of steam so is a burner to gas and the development of light." While this statement was applied to open flame standard burners, it will apply with equal force to all incandescent mantle lamps.

The gas sold for illuminating purposes in this country is largely confined to water gas, coal gas and various mixtures of the two. Of the two straight gases, water gas is the more largely used,

[1] Public Lighting by Gas and Electricity, page 190 to 196.

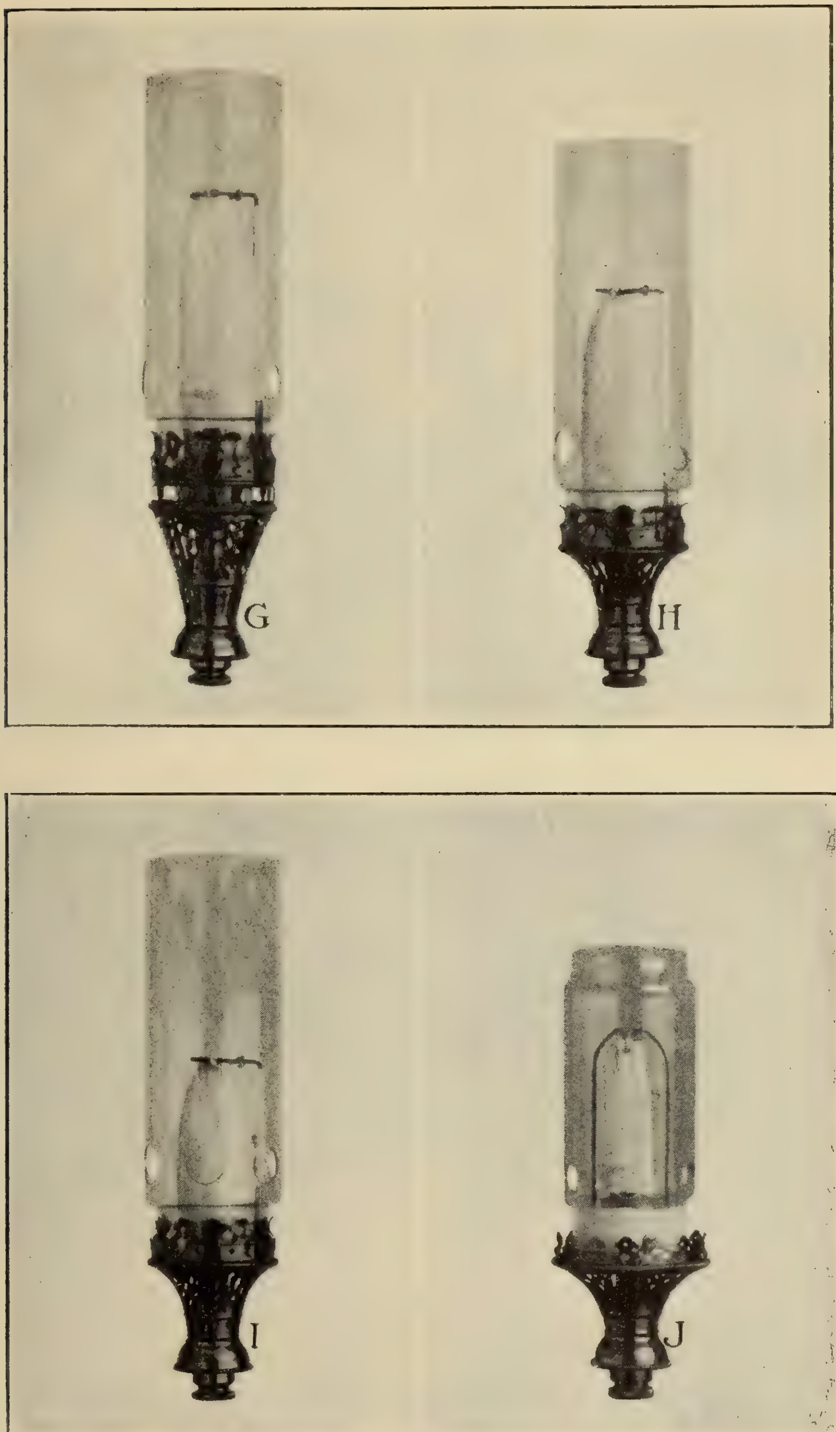


Fig. 2.—Upright incandescent mantle lamps.

while the proportions in the mixed gas vary so greatly that any investigation of lamp performance with a mixed gas would be largely representative for that particular mixture only and might not hold with a different mixture nor with either straight water or straight coal gas.

All the tests and observations here reported were made with water gas of a known quality taken from a special holder of ample capacity for each series of tests.

It is generally known that the "duty" (light output per cubic

Fig. 3.—Inverted incandescent mantle lamp. K—clear cylinder. L—frosted tip cylinder.

foot of gas consumed per unit of time) that is, the specific output is greater with incandescent mantle lamps than with open flames, but as stated above there has been comparatively little information available on the performance of these sources under various low pressures from one to eight inches of water.

The writer stated[1] a year ago, that of over eight hundred gas

[1] *Transactions* American Gas Institute, 1909.

companies in this country reporting on their pressures, 17.6 per cent. gave pressures between 1 and 2 inches; 63. per cent. gave pressure between 2 and 3 inches; 19.3 per cent. gave pressures between 3 and 6 inches, and that "experience would tend to show that the maximum pressures are rather higher than as shown above."

That the tests here given might have the greatest practical value, the following equipment was used and investigated at all pressures from one to eight inches.

TABLE I.—Open Flame Burners Illustrated in Fig. 1.

Test	No. of burners	Rated consumption, cu. ft. per hour	Kind of burner
A	1	3	lava tips
B	6	6	lava tips
C	2	8	lava tips
D	4	5	aluminum tips
E	1	5	aluminum tips governor burner
F	6	7	bray high-pressure burners

TABLE II.—Upright Incandescent Mantle Lamps Illustrated in Fig. 2.

Test	No. of burners	Kind of burner and equipment
G	10	Upright burner with deck plates, 6¾ in. air-hole chimneys and 4 in. × 1⅛ in. cotton mantles.
H	10	Upright burners with deck plates, 6¾ in. air-hole chimneys and 3½ in. × 1⅛ in. cotton mantles.
I	10	Upright burners with deck plates, 6¾ in. air-hole chimneys and 2½ in. × 1 in. cotton mantles.
J	10	Upright burners with deck plates, 5¼ in. air-hole chimneys and 2½ in. × ¾ in. cotton mantles.

TABLE III.—Inverted Incandescent Mantle Lamps Illustrated in Fig. 3.

Test	No. of burners	Kind of burner and equipment
K	9	Inverted burners with clear cylinders, ramie fiber mantles.
L	12	Inverted burners with frosted tip cylinders and ramie fiber mantles.

In tests A to F readings were taken of the intensity in a horizontal direction in a plane normal to the flat side of the flame

at each pressure, 1, 2, 3, 4, 5, 6, 7 and 8 inches. One burner in each of the series B, C, D, and F which gave values nearest to the average for each test together with burners A and E,

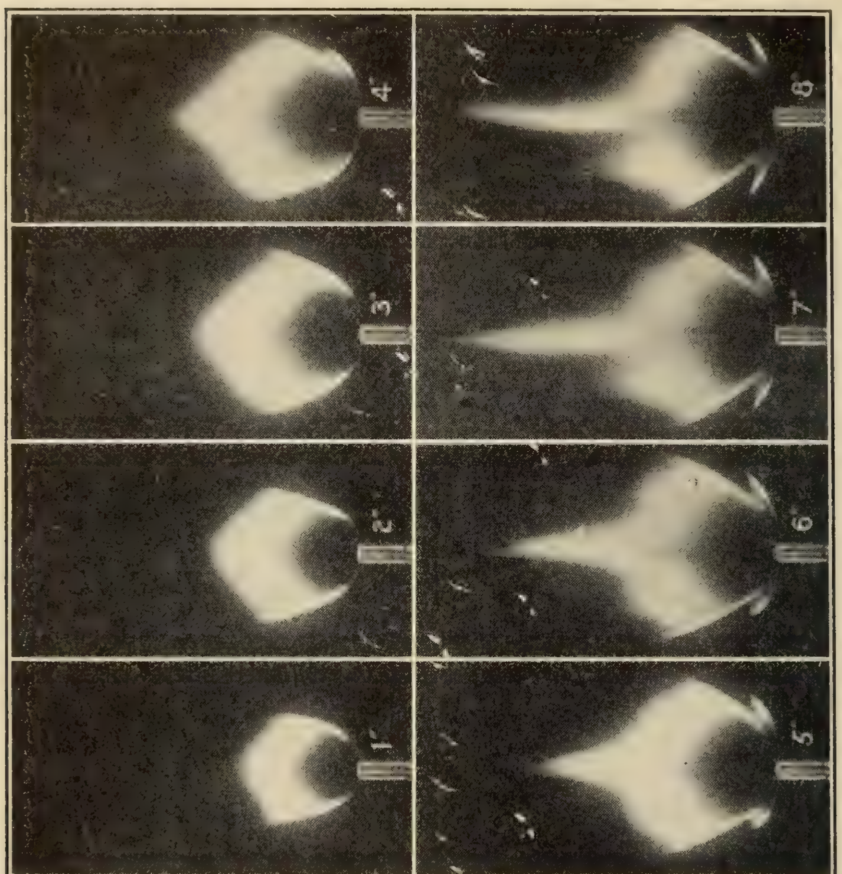


Fig. 5.—Open flame burner F with pressures from 1 to 8 in.

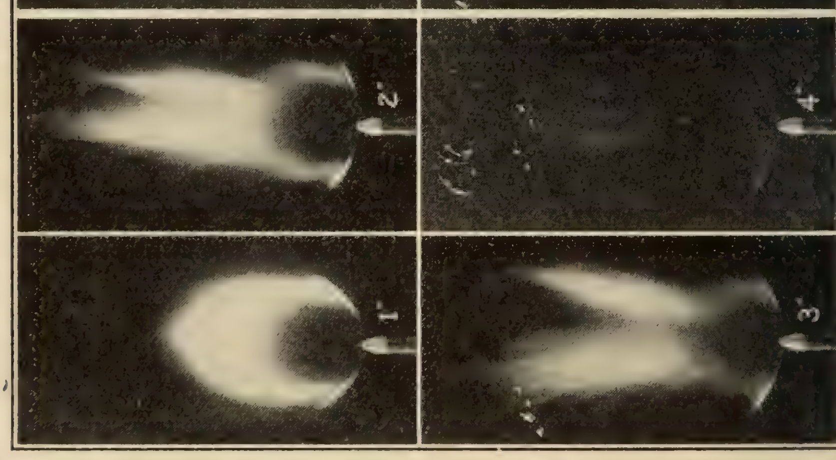


Fig. 4.—Burner D 1 to 4-in. pressures.

were then read at 2 in. pressure at each 15° point in the horizontal plane and also in the vertical plane. In reading the former the 0° angle was taken at the edge of the flame while in the reading

of the latter the 0° angle was taken below the burner, and the 90° angle normal to the flat side of the flame, the same as in the horizontal readings.

Each of the burners used in these tests was then photographed at each pressure, and shows very clearly the effect of pressure on the different flames. Figs. 4 and 5 showing burners D and F are typical examples of the worst and best of the six sets.

Figs. 6 and 7 give the vertical and horizontal distribution curves at 2 in. pressure, and Fig. 8 the specific output, horizontal candle-power, and consumption of each set of burners at the various pressures noted.

Corrections in candle-power and consumption were made for the barometric, humidity and temperature conditions present when the tests were made. The open flame tests at two inch pressures, Figs. 6 and 7 were made with water gas rated at "19.78 candle-power," having a calorific value of 623 British Thermal Units and a specific gravity of 0.661.

While the vertical and horizontal distribution of light about these burners is not symmetrical in either the horizontal or vertical planes, it is so nearly so that the horizontal candle-power taken normal to the side of the flame may be assumed to be the mean horizontal value to which a reduction factor of unity may be applied for mean spherical candle-power. As the horizontal readings bear a direct relation to the total flux, they may be used for the comparison of one burner with another.

TABLE IV.—OPEN FLAME BURNERS AT 2-IN. PRESSURE.

Burner	Horizontal c-p.	Consumption cu. ft. per hour	Specific output c-p. per cu. ft. per hour
A	14.34	6.45	2.22
B	21.9	8.2	2.66
C	36.0	10.5	3.43
D	21.0	9.55	2.2
E	15.6	4.45	3.5
F	20.5	5.24	3.92

Reference to Fig. 8 shows that with the lava tip burners, A, B, and C, the point of maximum light output lies between 2 and 3 in., beyond which points the light falls off rapidly towards zero at eight inches, the flame being almost blown out. The consumption practically follows a straight line increasing from 4.14, 5.56 and 7.8 at one inch to 14.16, 17.8 and 22 cu. ft. per hour

respectively at 8 in. The point of maximum duty is somewhere below 1 in. pressure.

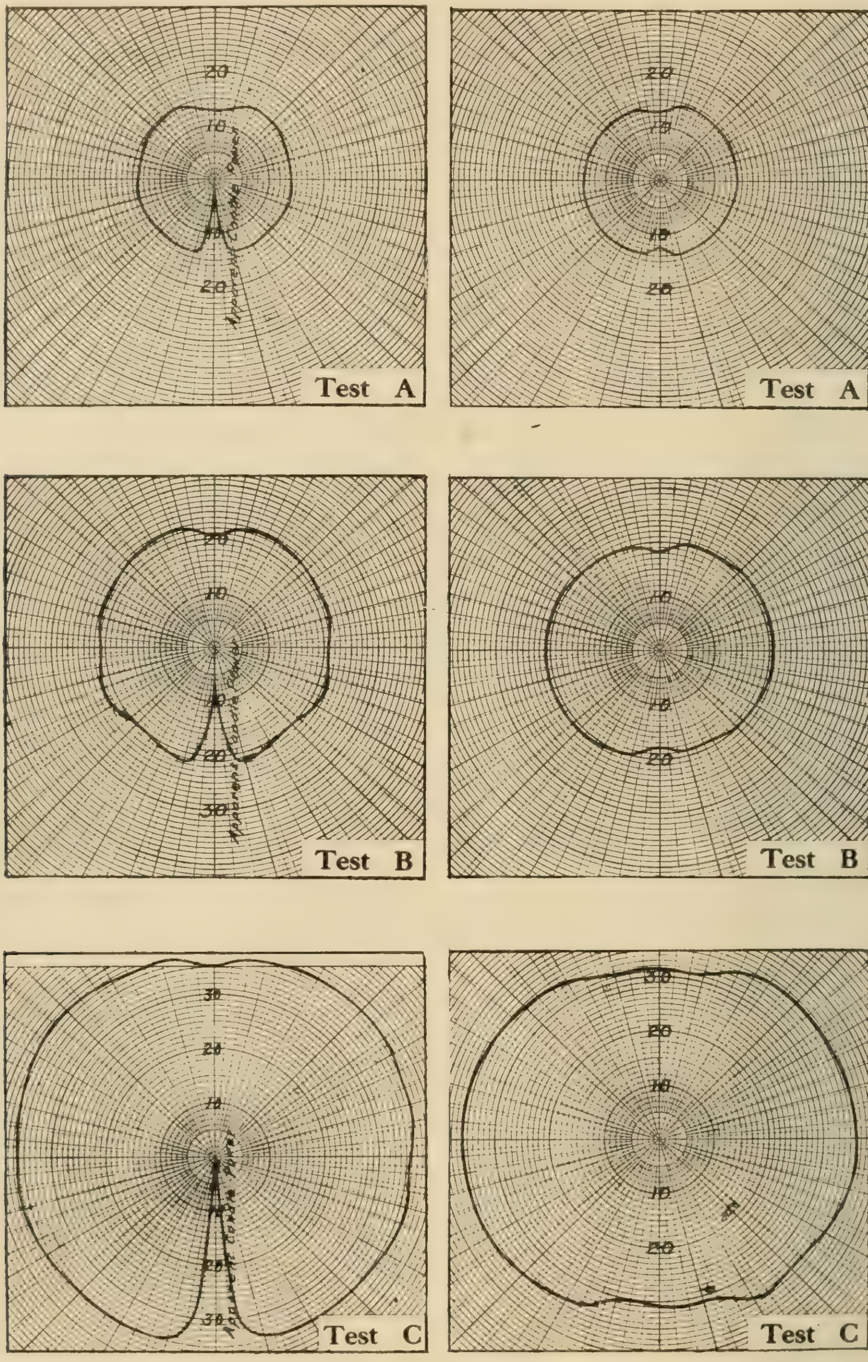


Fig. 6.—Vertical and horizontal distribution of light about open flame burners "A", "B", and "C".

The so-called 5-ft. aluminum tip burner D, made the poorest

showing at all pressures investigated. The 5-ft. aluminum tip governor burner E, was somewhat better, although the point

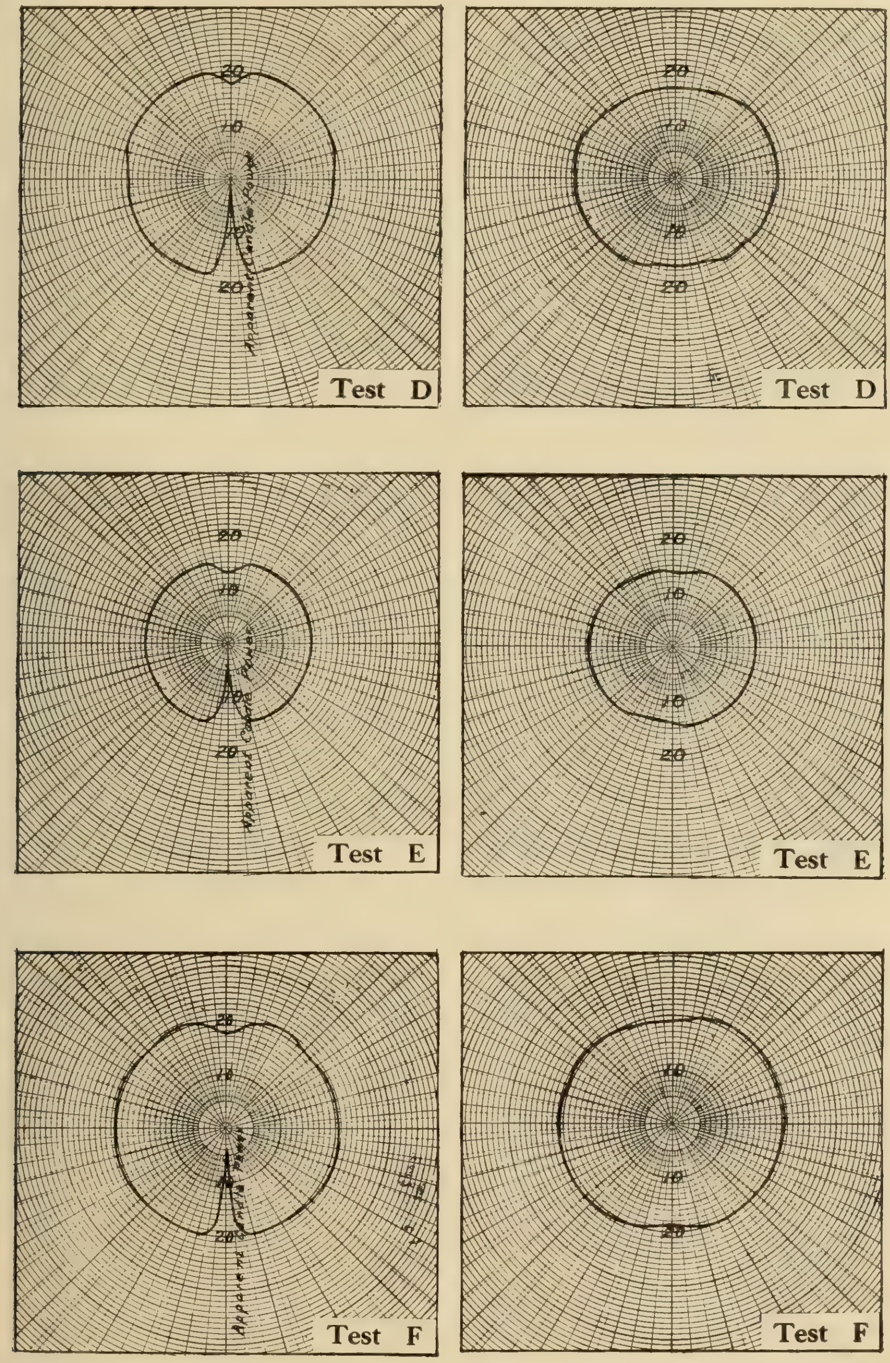


Fig. 7.—Vertical and horizontal distribution of light about open flame burners "D", "E", and "F".

of maximum specific output here also was below the 1-in. point.

The horizontal candle-power varied from 11.38 at 1-in., reached the maximum of 19.22 candle-power at 5-in., then dropped off to

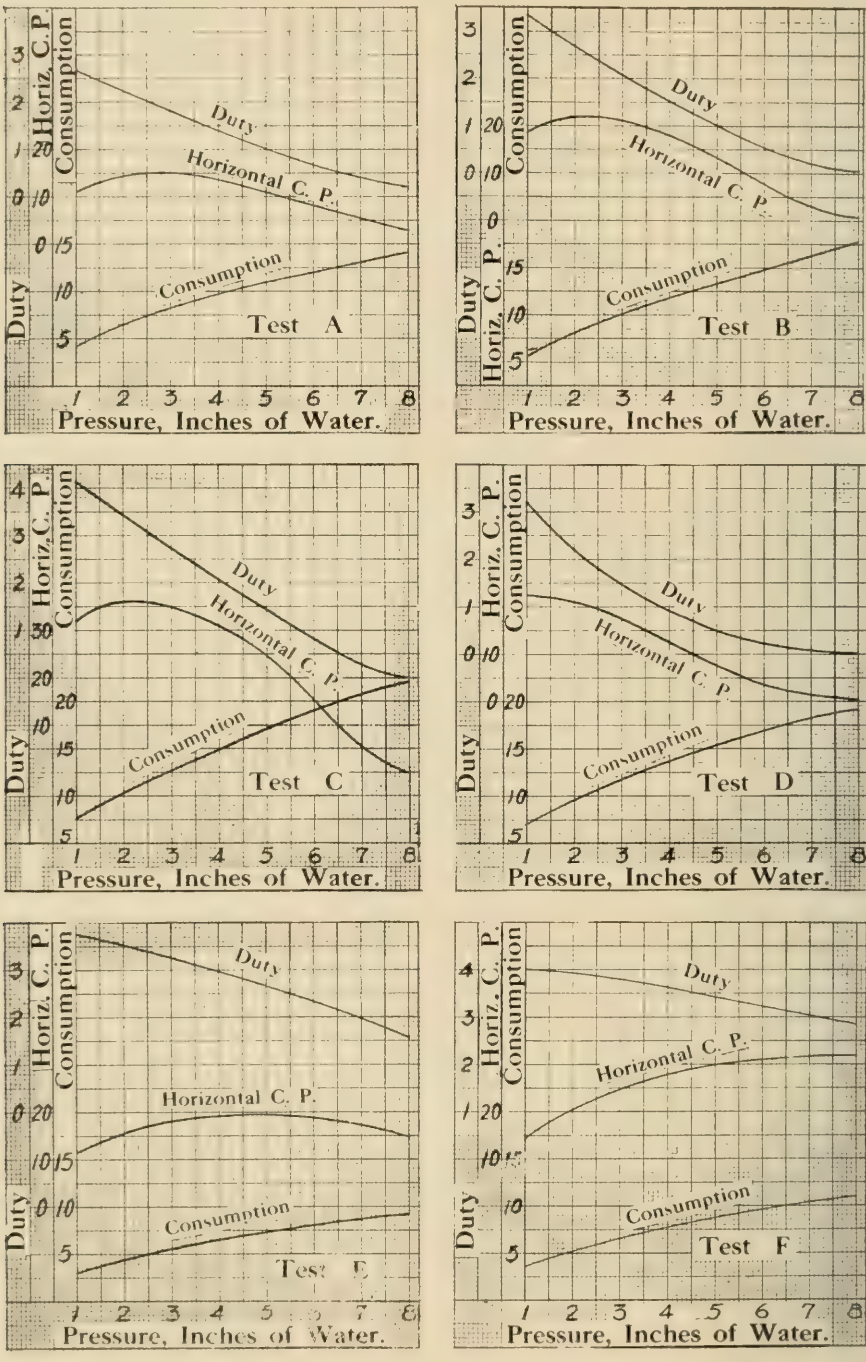


Fig. 8.—Performance of open flame burners at various pressures.

14.56 candle-power at the 8-in. pressure. The consumption steadily

increased from 3.03 cu. ft. at 1 in. to 9.2 cu. ft. at 8 in. The candle-power per cu. ft. per hour falling off from 3.76 to 1.58, or by slightly over 58 per cent.

The best burner throughout was shown to be the special high pressure, F. With these burners, the light output increased, the point of maximum being somewhere beyond the 8 in. point. Although the consumption at 8 in. had more than doubled, the specific output fell off only 29 per cent. from 1 in. to 8 in., the highest pressure taken.

These tests were carried to an extreme, inasmuch as most

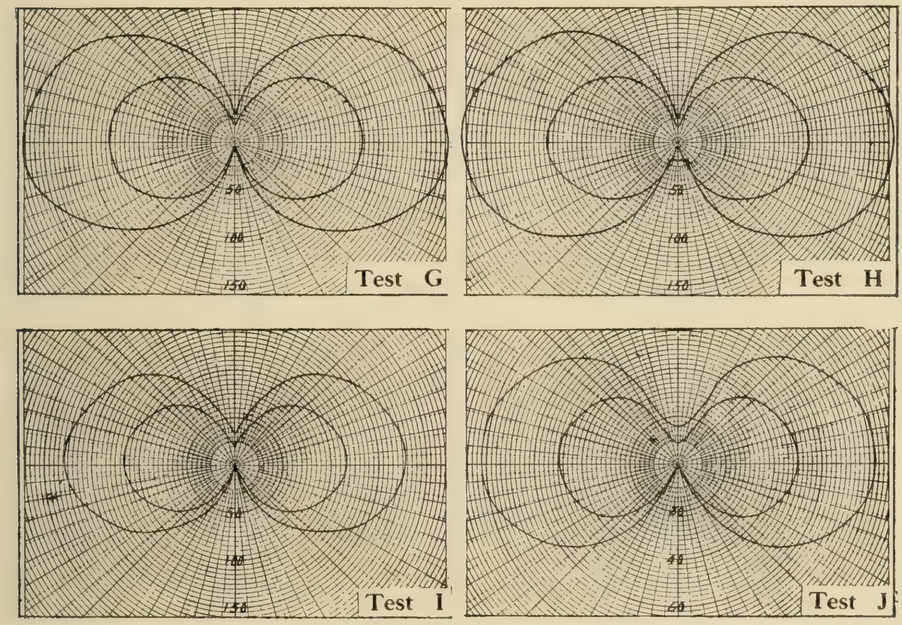


Fig. 9.—Vertical distribution of light about upright mantle lamps at 2-in. and 8-in. pressures respectively.

users would have reduced the pressure and flow of gas by turning off the key at the burner long before the flame reached the blowing out point. As this may not always be done, however, the results here given show conclusively what can be expected.

UPRIGHT INCANDESCENT MANTLE LAMPS.

Ten upright lamps of each kind, G, H, I, and J shown in Fig. 2, were taken from the regular stock awaiting shipment, were assembled, connected up and used for sometime before being placed on the horizontal bar photometer for readings at 1, 2,

3, 4, 5, 6, 7, and 8 in., each lamp being adjusted at each pressure for the maximum candle-power, this maximum being judged by the eye without the aid of the photometer; in other words each lamp was given a "fitter's adjustment." The purpose of the entire test was not to show the highest light output nor maximum "specific output," which might be possible, but to secure average results which would be readily reproducible and which would represent, as nearly as possible, the performance which might reasonably be expected in practice with similar equipment under somewhat similar conditions.

After running the entire series through at the various pres-

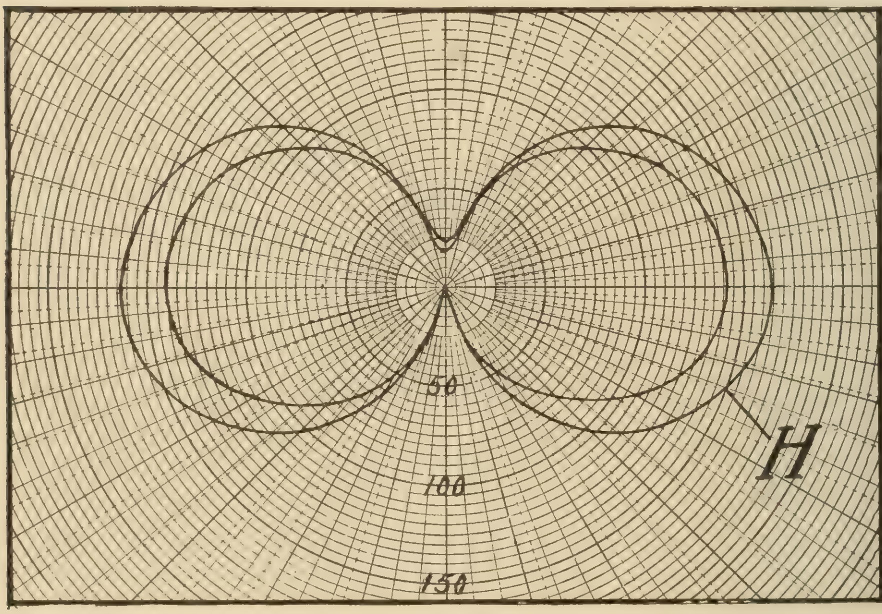


Fig. 10.—Vertical distribution of light about upright lamp H with two different chimneys.

sures above stated, one lamp from each class was chosen, this lamp being the one which in total light output and "specific output" most nearly represented the average. Each of these lamps was then placed on the radial photometer and read at each 15° angle in the vertical plane at 2-in. and at 8-in. pressures, see (Fig. 9). Corrections, were applied, based on the average horizontal values from the series of ten lamps, in order that these tests on the one lamp might be properly representative. To just what extent this average (with the fitter's adjustment) gives conservative results may be best appreciated by a comparison of

the two curves of Fig. 10. The largest curve marked H was the average lamp in the H series, and was especially adjusted with the aid of the photometer for maximum candle-power at minimum consumption. The smaller curve shows the distribution from the same burner and mantle with a cylinder differing from the regular one in that the air-holes were ⅛ in. less in

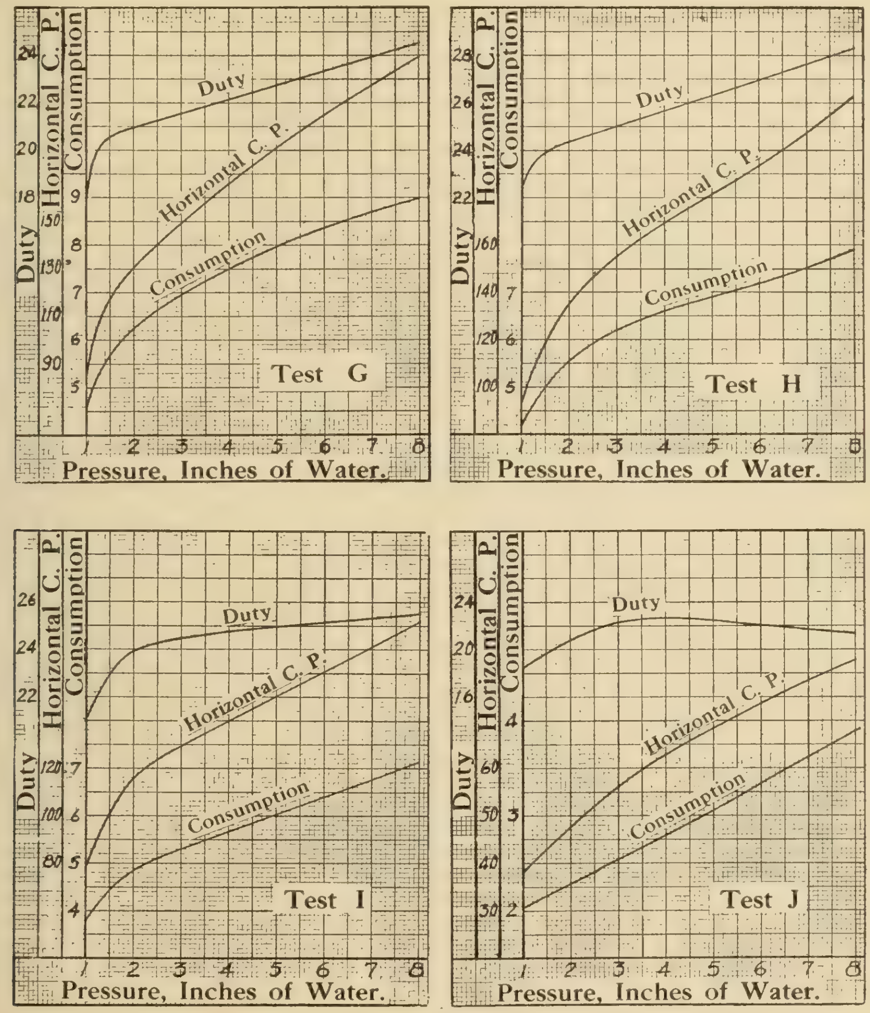


Fig. 11.—Performance of upright mantle lamps at various pressures.

diameter. The equipment with the best possible adjustment and large air-hole chimney shows an increase over the fitter's adjustment of 10.1 per cent. and an increase of 14 per cent. over the small air-hole chimney; which facts illustrate very clearly the effect of good adjustment and mechanical design on the efficiency of a lamp as a producer of light.

TABLE V.—RESULTS AT 2.5-IN. AND 8-IN. PRESSURES WITH UPRIGHT INCANDESCENT MANTLE LAMPS G, H, I AND J.

Lamps	G		H		I		J	
Pressure in inches of water	2.5	8	2.5	8	2.5	8	2.5	8
Consumption, cu. ft. per hour	6.64	9.0	5.95	7.9	5.08	7.11	2.41	3.92
Mean upper hem. c-p.	116.9	190.5	116.3	177.0	100.5	145.0	44.0	66.5
Mean lower hem. c-p.	99.4	162.0	104.8	159.0	83.4	120.0	37.6	56.7
Mean spherical c-p.	108.1	176.2	110.5	168.0	91.9	132.5	40.7	61.6
Lumens, upper hemisphere	733.0	1194.0	732.0	1110.0	632.0	910.0	276.0	417.0
Lumens, lower hemisphere	625.0	1017.0	658.0	995.0	524.0	753.0	236.0	356.0
Total lumens	1358.0	2211.0	1390.0	2105.0	1156.0	1663.0	512.0	773.0
Total lumens per cu. ft. per hour	204.0	246.0	235.0	266.0	228.0	234.0	212.0	197.0
Per cent. consumption	100.0	135.5	100.0	133.0	100.0	140.0	100.0	162.5
Per cent. total flux—lumens	100.0	163.0	100.0	151.0	100.0	144.0	100.0	151.0
Per cent. total lumens per cu. ft. per hour	100.0	121.0	100.0	113.0	100.0	102.6	100.0	93.0
Horizontal candle-power	140.6	220.0	146.5	223.0	123.2	181.0	52.1	83.0
Horizontal c-p. per cu. ft. per hour	21.20	24.47	24.70	28.26	24.30	25.47	21.60	21.20
Reduction factor (per cent. hor. c-p. to M. S. C. P.)	76.8	80.1	75.5	74.2	74.6	73.2	78.1	74.1

In Fig. 11 is shown the characteristic performances of the series of ten lamps each of G, H, I and J illustrated in Fig. 2. G, H, and I do not show any falling off in "duty" at pressures below 8 in. It is, however, clearly indicated that these lamps should be used on pressures of over 2-in. The light production

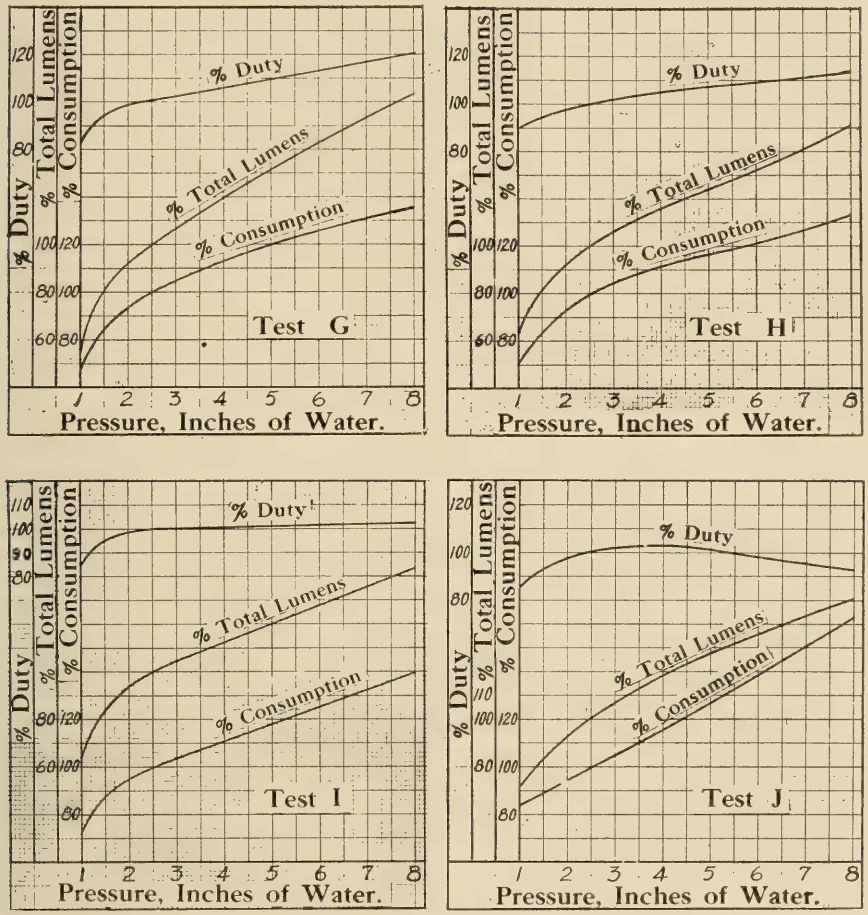


Fig. 12.—Characteristics of upright mantle lamps plotted in per cent. values with 2.5-in. pressure as the base.

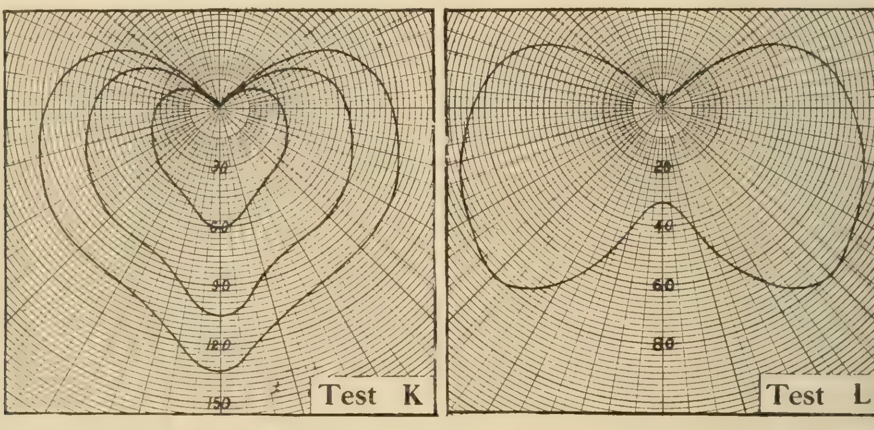
and "specific output" increasing rapidly from the 1-in. to 2-in. pressure points.

The lamps of series J show a maximum duty at about 4-in. pressure, falling off very slightly up to the 8-in. pressure point.

Table 5, bringing the results at the 2.5-in. pressure and the 8-in. points together, shows very clearly the considerable effect due to pressure. It might be here stated that 2.5-in. pressure has been assumed as more nearly representative of the average supply in this country and was therefore adopted by a large manu-

facturer of gas lamps as the standard pressure at which to make light distribution tests with various lamps and accessories.

The tests here recorded show rather conclusively that reports on the light output and gas consumption of different lamps at different pressures may in no way be considered comparable unless the characteristic of the performance of each lamp is known at the various other pressures. To calculate the probable resultant illumination with any gas lamp, it is also necessary not only to have this information but also that pertaining to the average pressure of supply. With an increase in light production of from 100 to 190 per cent. depending upon whether the pressure is 1-in. or 8-in. and depending also upon the equipment used, is surely a point worthy of much consideration.



Figs. 13 and 17.—Vertical distribution of light about inverted mantle lamps "K" at 1-in, 2.5-in. and 8-in. pressures, and with frosted tip cylinder at 2.5-in. pressure.

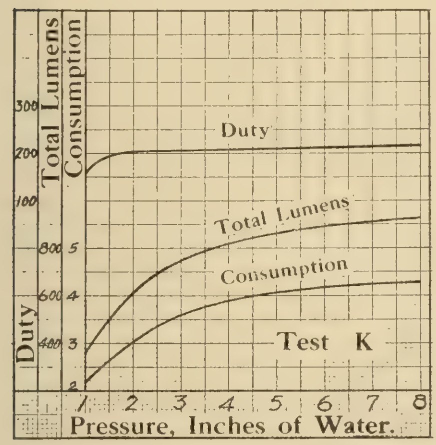
In Fig. 12 is given the characteristic curves of lamps G, H, I and J plotted in per cent. values with the results at 2.5-in. pressure at the base, showing the relation between the total lumens generated per cu. ft. of gas consumed per hour, and the consumption, with the pressure.

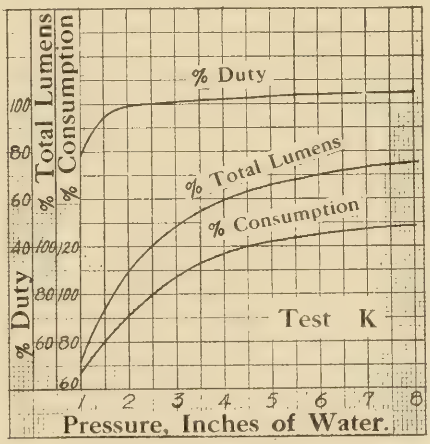
A distribution curve of lamp H, a combination which has a large field, if made on water gas at 2.5-in. pressure could be used for the calculation of the intensity of illumination on a given plane only where the supply pressure would be 2.5-in. Knowing the light output from this lamp at all other pressures up to 8-ins., the proportionate illumination which would result if the average pressure of the supply was 4-in. may be readily determined and would be 1.16 times calculated that as

is indicated on the "per cent. total lumen" curve as plotted. On the other hand at 1.5-ins., the illumination would be 82 per cent. of that calculated at 2.5-ins., and for installations where the pressure will average 1.5-ins. the calculated results at 2.5-in. pressure should be reduced by this factor. Conversely, the results from illumination measurements of various installations may be brought to compare with other tests by reducing or increasing as the case may be, all values to the 2.5-in. pressure basis, using in each instance the characteristic curves for the particular equipment under test.

INVERTED INCANDSCENT MANTLE LAMPS.

Tests K and L were carried out on lines similar to those





Figs. 14. and 15.—Performance of inverted mantle lamps " K " at various pressures.

above described for G, H, I and J with the exception that full radial readings at each 15° in a vertical plane from 0°, the nadir point, to 180° were taken on each lamp. Where the horizontal readings on the open flames and the upright lamps maintain a certain fixed relation to the total flux, it was found that the readings at 90° on the inverted lamps would vary to a greater or lesser extent with lamps giving practically the same total light flux, but that a curve can be drawn between pressure and the candle-power at 77° 30′ which, within 1 per cent. has the same characteristic curve variation as that between the total flux and the pressure in inches of water. It is a rather peculiar coincidence also that the candle-power at this angle when multiplied by 10 gives the total lumens generated.

It was also found that when a curve was plotted in the proportionate scale values of 100 lumens to 1-in. pressure with the total lumens as abscissa, and pressure in inches of water as ordinate, it conformed very closely to the arc of a circle the center of which was on the base line at 7.15-in. pressure. The maximum variation between the circle and flux-pressure curve was 0.5 per cent. from 1.5-in. to 6.5-in. pressure.

From the circle, the following formula was derived:—

$$300 + 100\sqrt{36.6 - (7.15 - P)^2} = \text{total lumens.}$$

Where P is the pressure in inches of water—(1.5-in. to 6.5-in.). Total lumens is the total light flux generated by lamp K, Fig. 3, with clear cylinder and ramie fiber mantle when adjusted to its maximum candle-power as judged by a fitter.

Upright Formula.—The following formula may be used to calculate the total flux from the burner shown as H in Fig. 2 for pressure from 2 to 8 in. water

$$95\left[138 + \frac{86\,P - 172}{6}\right] = \text{total lumens.}$$

It is readily seen that from these formulas the total flux may be calculated for the most usual low pressures. Reference to Fig. 13 shows that the effect of pressure must be taken into account with these lamps also, although not to the extent necessary with the upright. Fig. 15 shows the lumens per cu. ft. per hour the total lumens and the consumption curves plotted against pressure.

This lamp gives so much better results above 2-in. pressure that the question of the supply pressure should be investigated before deciding upon its use. The point of maximum duty here, as with the upright lamps, is beyond 8-in. Satisfactory results, however, should be secured at any point above 2-in. pressure. Fig. 14 gives the curves for duty, total lumens and consumption in percentage values with the 2.5-in. pressure as a base.

Table VI shows the values read from the curve Fig. 15 for each pressure change of 0.1-in.

Test L was with 12 lamps, similar to those in test K with the single exception that a frosted tip cylinder was used. The characteristic performance of these lamps are exactly similar

TABLE VI.—FLUX AT VARIOUS PRESSURES WITH 2.5-IN. PRESSURE AS UNITY TAKEN FROM FLUX-PRESSURE CURVES.

Pressure	Flux	Pressure	Flux	Pressure	Flux
1.0	0.515	3.7	1.164	6.0	1.296
1.5	0.719	3.8	1.173	6.1	1.299
1.6	0.753	3.9	2.182	6.2	1.302
1.7	0.789	4.0	1.191	6.3	1.305
1.8	0.823	4.1	1.20	6.4	1.309
1.9	0.855	4.2	1.209	6.5	1.312
2.0	0.885	4.3	1.214	6.6	1.316
2.1	0.913	4.4	1.221	6.7	1.319
2.2	0.936	4.5	1.229	6.8	1.321
2.3	0.960	4.6	1.233	6.9	1.324
2.4	0.980	4.7	1.238	7.0	1.327
2.5	1.000	4.8	1.244	7.1	1.329
2.6	1.015	4.9	1.25	7.2	1.331
2.7	1.035	5.0	1.255	7.3	1.333
2.8	1.05	5.1	1.26	7.4	1.335
2.9	1.064	5.2	1.265	7.5	1.336
3.0	1.079	5.3	1.269	7.6	1.338
3.1	1.092	5.4	1.273	7.7	1.339
3.2	1.106	5.5	1.277	7.8	1.341
3.3	1.119	5.6	1.281	7.9	1.343
3.4	1.131	5.7	1.285	8.0	1.344
3.5	1.143	5.8	2.289		
3.6	1.153	5.9	1.293		

to those in test K shown by Figs. 14 and 15, excepting that the total flux is reduced 2.5 per cent. due to the frosting of the cylinder. Fig. 16 shows the distribution of light about this lamp at 2.5-in. pressure. Where with the clear cylinder the candle-power intensity at 77° 30′ represented one-tenth of the total flux in lumens, with the frosted tip cylinder the angle is 82° 30′ for a similar result.

DISCUSSION.

Mr. G. S. Barrows:—In the reports of pressures from various companies in the country, were the pressures as reported taken at the head of the service or at the tip burner? Were the mantles that were tested on the upright lamps the same in G and H? Apparently one mantle was a long one. Were the mantles seasoned? The author speaks of the fitter's adjustment of the mantle burners when being tested, but he did not give any fitter's adjustment to the open flame burners. Why is it not as fair to make a fitter's adjustment in one case as in the other?

Mr. Ward Harrison:—Do the comparisons given for the companies reporting one to two inch pressure, etc., refer to the number of companies reporting or to their output in million cubic feet per day? Was the upright mantle used the regular mantle that is commonly sold? Is the inverted mantle regularly supplied now with the ramie fibre? If the pressure varies while the lamp is adjusted for one pressure, what effect has the variation on the candle-power? What percentage does the author allow as a general thing between the fitter's adjustment and an adjustment for maximum candle-power on a photometer?

Mr. S. W. Ashe:—The author states that the corrections in candle-power and gas consumption were made for the barometric, humidity and temperature conditions present when the tests were made. I should appreciate knowing how much effect these different things have upon the candle-power of the mantle. I should also be pleased to learn how many inches of pressure is used for natural gas. What effect has a variation in calorific value of the gas upon the candle-power in an inverted mantle? Other conditions remaining the same, I should imagine that there would be a marked variation, and some tests which I have made indicate that a large variation exists.

Dr. C. H. Sharp:—How were the corrections made in the candle-power for the humidity?

Mr. H. T. Owens:—The author says one of the most important considerations in gas illumination is the effect of pressure upon the lamps. Instead of the effect of the pressure upon the lamps, I should say that one of the most important considerations was to regulate that pressure, and when the installation is of sufficient size to require extensive calculations to determine the intensity of illumination, a pressure regulator should in all cases be employed. However, pressure is not of so great importance as is the quality of the gas.

Mr. William J. Serrill:—Concerning the extent of variation of pressure that exists in gas practice, I should say that, while there may be in many cases considerable variation at different times of the day, during the lighting hours the pressure for a given consumer would be reasonably uniform throughout the year. There are I imagine in every city some customers who get uniformly higher pressures during the lighting hours than

other consumers do. There are probably sections in every city where the pressures are somewhat lower than the ideal one. In Philadelphia there are a good many holder stations, and hence the pressure is regulated so that probably 90 per cent. of the consumers have nearly the ideal pressure throughout the twenty-four hours and throughout the year. The aim is to have the pressure in the mains at from 3 in. to 3.5 in. water column. Are the incandescent gas mantles that are put on the market serviceable under eight inches of pressure, that is, will they withstand that much pressure in actual use?

Mr. C. S. Rowe:—Has the author any general information, even if not definite, on the effect of variations in pressure on the life of mantles. It seems to me that the candle-power variations, while they are important, are perhaps only equally so with the effect on life.

Mr. P. S. Millar:—In obtaining the curves for variation of candle-power with pressure, was the lamp adjusted at each pressure for maximum candle-power, or was it given one initial adjustment and left?

It would be interesting to learn the author's views as to why relatively so few mantles are used in this country. Is it not true that there are great differences in the quality of gas lamps to be had in this country? If that is so, to what extent are the better class of lamps used? Are the gas companies doing anything to promote the use of the better gas lamps, thereby promoting their consumers' interest in the matter?

I wish to express my appreciation of this paper. It is certainly a valuable contribution to our TRANSACTIONS.

Mr. Barrows:—When incandescent mantle gas lamps were first put on the market, about 1888 or 1889, there was almost no sale for them anywhere in this country except in the natural gas region. From 1888 to 1889 up to about 1892 or 1893 the mantle manufacturing company was kept alive by the sales of mantles and lamps through the natural gas region, relatively few lamps being sold for use with manufactured gas.

The probable reason for the higher efficiency of the lamps with natural gas was the universally higher pressure under which the lamps were used. While it is true that natural gas has higher calorific value, running from, say, 900 to 1,200 B. t.

u.'s per cubic foot, as against an average of perhaps 600 B. t. u.'s per cubic foot of manufactured gas, the increase in the pressure was probably what sold the lamps in the natural gas regions; in many cities where natural gas was sold under low pressures, that is, two or three inches, the lamps were not a success. The pressures under which they were used in natural gas regions varied anywhere from a quarter of a pound up to ten pounds. I have seen lamps that have been in use for a period of probably five or six years, the brass parts of which are in practically as good condition as the day they were put in; the mantles and the globes are used up very rapidly under the higher pressures; unless the lamps are kept carefully adjusted, the gauzes are also burned under the higher pressures. However, it was the higher pressure that kept the market for the old gas mantle alive until the thorium mantle was developed.

Mr. Hanlon:—As to what the gas companies are doing to insure good lamps being placed on the market, I may say that most gas companies that handle lamps themselves must of necessity handle the best lamps they can get. The gas companies, like electric light companies, are selling service, and if they do not give the service, naturally they cannot expect their consumers to be satisfied. It behooves the gas companies to handle the best lamps they can. It is only through the dealers that have no interest whatever in the service, but just in the profits that they make on the sale of the lamps, that the standard of lamps has been lowered. I dare say in every city there are a half dozen people handling cheap, inferior lamps. A person can buy a lamp mantle at prices ranging from 19 cents to $1.50. The $1.50 lamp is usually sold by the gas company, and the 19 cent lamp is usually handled by the dealer. The dealer has no interest whatever in the service, but the gas man has an interest in the service and naturally must sell the best goods.

Mr. R. S. Hale:—Will the shape of the curves shown by the author be different towards the end of the life of the mantle? When a mantle has been used say 300 or 400 hours, will the shape be different or the same as when the mantle was new?

Mr. Serrill:—On the question of gas pressure, I think the tendency among gas companies in this country, as it is abroad,

is to increase the pressures. Higher pressures prevail more generally now than they did five years ago, and I imagine five years hence still higher pressures will prevail. An enormous quantity of gas is used for fuel appliances, but all those appliances can be adjusted to the higher pressures, and even they give better results with higher pressures, just as it is true of the incandescent gas lamps.

Reference was made to the quality of the gas as affecting incandescent gas lamps. My impression is that the only feature of quality, apart from the pressure, is the gravity of the gas. A change in the gravity produces as great an effect as a change in the pressure.

Mr. Macbeth:—The values of pressures recorded in the paper were really obtained from a directory. As a matter of fact, as stated in that report, I do not believe that the pressures as given were representative. They were what the gas men would like to have had. The pressures are various throughout the different parts of the country. In some towns, which are quite hilly, the pressures are greater in one part of the town than in another.

As to the length of the mantles in the tests G and H, one was 4 in. × 1⅛ in. and the other mantle was 3.5 in. × 1⅛ in. The mantles used were not what would be stated as seasoned; they had been used for about 100 hours. The open flame was not given a fitter's adjustment, because, as stated before, a fitter does not adjust the flame. That is usually done by the householder or the individual who applies the match. Just what adjustment would be used is rather difficult to determine; consequently the key was left open, subject to the pressure as stated; each reader of the paper is left to judge at just which point and to what pressure he would turn the key. The curves will show what the result would be.

The gas pressure report was given for 800 companies throughout the entire country, not 800 pressures as was assumed.

Concerning the effect of pressure, where the two vertical distribution curves marked H are given, both were taken with the maximum candle-power adjustment as judged with the photometer, the ten per cent. difference being due entirely to this adjustment. In other words, they were observed with the same

lamp which gave results nearest to the average in the regular test; the 14 per cent. less light flux was also observed with the maximum adjustment but with the chimney having the smaller air holes.

The barometric and temperature corrections were made for all the tests while the additional humidity corrections were made for the pentane lamp and gas flame tests only. These corrections are the ones regularly made to bring the results to standard conditions.

Mantles have been used at pressures as high as 270 inches. The effect of calorific value on a mantle I do not believe has been fully determined. Two laboratories with which I am acquainted take these various observations on all their tests, that is, the calorific value of the gas, its specific gravity and all other possible qualifications of that gas. Undoubtedly at some not very distant date, information will be available on this particular point. The European opinions given thus far differ considerably. Two authorities, for instance, each of whom has been recognized, give widely different opinions.

Concerning the effect of pressure on lamps, it may be said that when a lamp is adjusted at 2.5 in. pressure and the adjustment remains fixed while the pressure is increased to 3, 4, 5 or 6 inches or reduced to 1 or 2 inches, the effect may be considerable, depending not only on the changes in pressure but also on the kind of lamp and mantle. It is very seldom, of course, that a householder would permit a flame to come above the mantle and perhaps above the chimney without turning it down at the key, while for lower pressures the adjustment of the burner is generally changed. However, there are remarkably few cities in which there are any such pressure changes during the ordinary lighting hours or during the time that a burner would be used. The remedy would not rest with the lamp manufacturer or the consumer but with the supply company. Observations made at all hours of the day and all hours of the night in the city in which I live showed that the changes in pressure during any two or three months did not exceed 0.3 in. of water from the normal of 3.0 in. I believe that in the last two years not more than two of the 12 lamps in my residence have been touched so far as adjustment was concerned. The only mantle

changed was one broken accidentally in removing the glassware for cleaning; the balance of the installation is just as when it was first made.

I believe a lamp, so far as the mantle is concerned, would be quite as serviceable under 8 in. pressure as under 3 in. because the high pressure is not on the mantle—it is on the burner orifice, and by adjusting down at that point the pressure is not greater on the mantle than it would be with a lower initial pressure. What is obtained at the high pressure is a better mixture of gas and air, the higher velocity of the jet in the check inducing a better air and gas mixture.

The question was asked: Why are so few mantles used in this country? I may get disliked when I give the answer but I believe that it is largely due to the general inactivity of the gas companies. A gas works was started in Baltimore over a hundred years ago, yet the large companies have only within the last two or three years been opening up show rooms and giving consumers an idea of what they can get and how they can best use gas. The mantle business and the gas business has been largely in the hands of the dealer, the peddler and the department store. I believe that if it were not for the very considerable value back of incandescent mantle lighting and the appreciation of that value by consumers, there would not be any gas lighting to-day. It has been hammered; it has been put down; it has been labelled as everything that is bad and if it was not for the few consumers who realize and appreciate the good value and quality of illumination possible there would be very much less gas used. There are now many gas companies who are establishing new business departments and are really going after the business properly and intelligently, and I believe that there are companies which now appreciate the value of the new business department adopting illuminating engineering methods in approaching the problem. The use of these methods will largely increase when their value is more generally appreciated.

Mr. Hale's question as to the shape of the light distribution curve from the mantle I am unable to answer fully. To the best of my knowledge I do not believe it would make any difference. In other words, the gradual reduction with time in light output from the mantle is uniform over the entire mantle. That

of course depends largely on the mantle also. There are available to-day mantles which do not shrink, which will hold their shape, hold their color, and continue to give their full candle-power. On the ordinary lamps and mantles with which we are so familiar, the considerable loss in light is largely due to the shrinkage of the mantle, the actual area being more or less reduced with age.

Mr. Serrill raised the question of the change in the gravity of gas and its effect. A change in the gravity of gas has the same effect as the reduction of the orifice in the check of the burner; in other words a change of adjustment. When the gravity is changed it simply means that at the works the adjustment on all the burners is being changed. Of course there would be difficulty if the change were greater than the lamp and the mantle would ordinarily take care of either as a decrease or increase in pressure or adjustment.

SOME SPECTRAL LUMINOSITY CURVES OBTAINED BY FLICKER AND EQUALITY OF BRIGHTNESS PHOTOMETERS.[1]

BY HERBERT E. IVES.

It is probably not necessary to discuss at any length before the Illuminating Engineering Society the difficulties of heterochromatic photometry nor the importance of a solution of the problem. Considerable work has been done in the past by numerous observers, among whom may be mentioned Dow, Abney, Tufts, Wild, Stuhr and Millar. Mr. Millar in an excellent paper before the Society's convention last year summarized the difficulties besetting this problem. It will, therefore, be assumed here that the importance of more knowledge of photometric methods applicable to our many-hued illuminants is appreciated and the difficulties in some measure understood.

In the present paper are given some results obtained in the progress of an extended investigation upon methods of heterochromatic photometry. The investigation is as yet far from completed and the results here presented form only a part of the work already done, and a smaller part of that yet to do. They form, however, a fairly complete investigation as they stand, and as they illustrate satisfactorily some of the chief phenomena appearing from the investigation in progress they are thought to be of sufficient interest to be presented now.

From the standpoint of accurate photometry, the most important problem at present is a comparison of the methods of equality-of-brightness and flicker photometry. Of the several methods of photometry of differently colored lights, these alone possess the quality of sensibility to a sufficient degree to warrant their use for measurement. Experiment has shown the criteria of these two methods to be different under certain conditions. The first problem undertaken in this investigation has been a study of the effect, on each method, of varying those conditions which affect brightness comparisons where color difference exists. The principal conditions in questions are: ab-

[1] A paper presented at the Fourth Annual Convention of the Illuminating Engineering Society, Baltimore, October 24 and 25, 1910.

solute illumination, size of photometric field, and differences in color vision in different observers.

The apparatus employed was designed with four objects especially in view. First, the scale of color should be of a standard character. Second, the flicker and equality-of-brightness measurements should be obtainable in the same apparatus without disturbing any of the critical conditions. Third, it should be possible to vary the illumination widely. Fourth, arrangements should be made to use several sizes of photometric field.

These objects were all attained by the use of a prism spec-

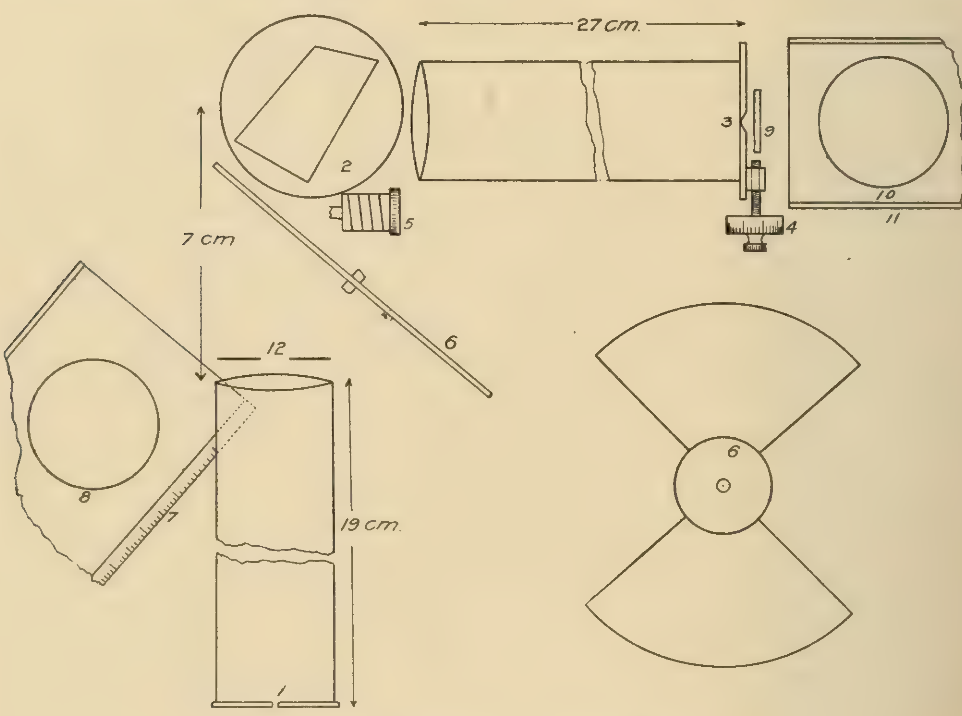


Fig. 1.—Arrangement of apparatus.

1. Observing slit; 2, prism table; 3, collimator slit; 4, divided drum; 5, wave-length drum; 6, white sector desk; 7, photometer bench; 8, standard lamp; 9, diffusing glass; 10, light source; 11, photometer bench; 12, diaphragm.

trometer in conjunction with a white sector disc, which in rotation formed a Whitman flicker photometer. With this instrument the spectrum of a normally operated tungsten lamp is formed upon an observing slit. The eye placed here sees the whole face of the prism illuminated by a narrow portion of the spectrum. The Whitman disc is situated between the prism and the observing telescope lens and is illuminated by a standard

4-watt carbon lamp mounted upon a photometer bar. When stationary the disc may be placed so that one of its edges bisects the field of view, thus permitting equality-of-brightness comparisons between the white surface and the spectrum color. The brightness of the spectrum field is altered by changing the width of the spectrometer slit. During the measurement of a "spectral luminosity curve" corresponding to one illumination, the position of the standard lamp remains unaltered, so that all of the measurements are made at that one fixed illumination. The spectral luminosity curves are then obtained by taking the reciprocals of the slit widths, correcting the values for the dispersion of the prism.

Different sizes of photometric field are obtained by diaphragms over the lens of the observing telescope. Three sizes are being used, and these, combined with about ten different illuminations, make thirty or more combinations of conditions under which comparisons of the two methods are being made.

The results of these will be reported upon later. The present report is upon a set of comparative measurements made by five different observers at two illuminations, for one field size. The five observers were all in some degree experienced in making observations and possessed no marked abnormalities of color vision. The two given by the initials H. E. I. and M. L. have made numerous observations with the apparatus and therefore were the most experienced. F. E. C. has had long experience in photometric work; C. F. L., considerable experience in photometric and other observations; P. W. C., the least experience in ordinary photometry, but is accustomed to visual observations in various optical instruments. The illuminations used were chosen in the light of the previous work by the two more experienced observers. The lowest is one at which it is still possible to make flicker measurements without too great difficulty; the highest is one beyond which from previous experience little change in the curves is to be expected. Both higher and lower illumination measurements with larger and smaller photometric fields have been made by the two most experienced observers, and their results will to some extent be drawn upon in interpreting the results from the measurements here given.

The two illuminations used were 250 and 10 units, where a

unit is an illumination of 1 meter-candle (0.0929 foot-candle) on a surface of magnesium oxide, as viewed through an artificial pupil of 1 sq. mm. (0.00155 sq. in.) area. Owing to the small size of this artificial pupil the effective illumination is much less than 10 or 250 meter-candles as ordinarily understood, probably about one-tenth as great. The field size here used is given by a circle 16 mm. (0.63 in.) in diameter at a distance of 20 cm. (0.78 in.) from the eye, therefore subtending an angle of 4½°, approximately the size of the yellow spot of the retina.

DETAILS OF THE MEASUREMENTS.

Measurements were made in the following manner: The spectrometer was adjusted to give a certain mean wave-length on the observing slit, the sector disc was placed so that half the field was "white," the other colored, and six readings made; the disc was then set into rotation, the speed adjusted by variable resistance in series with the motor, and six flicker readings made. This was done for twelve points in the spectrum, alternating on the red and blue sides. The slit openings, speeds, etc., were read by an assistant, except in the case of the two observers H. E. I. and M. L. who read their own observations.

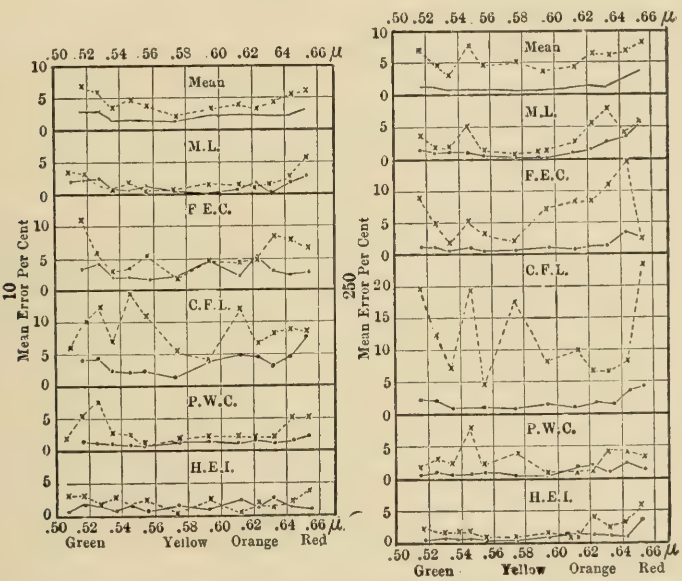
The results of the measurements are given largely in the form of curves plotting the observations in certain combinations with each other. The chief phenomena illustrated are: (1) Relative sensibility of the equality of brightness and flicker methods. (2) Effect of changing illumination with each method. (3) Relative position of luminosity curves given by each method at both illuminations. (4) Relative positions of luminosity curves derived by all observers, with their mean values.

RELATIVE SENSIBILITY OF THE EQUALITY OF BRIGHTNESS AND FLICKER METHODS.

A measure of the relative sensibility of the two methods is obtained by taking the mean error of setting. In Fig. 2 are plotted the mean errors for each observer at 10 illumination units for various points in the spectrum, from the deep red at 0.66 μ to the bluish green at 0.51 μ The mean flicker errors are given by the full line, the mean equality-of-brightness errors by the dashed line. In Fig. 3 are given the same quantities as obtained from observations at 250 illumination units. Several

facts are here brought out clearly. First, the flicker method is for all parts of the spectrum several times as sensitive as the equality-of-brightness method, the relative sensibility differing for different observers, but always favoring the flicker method. Second, the difference in sensibility between the methods is greater at high illuminations than at low. At the lower illumination the equality-of-brightness sensibility becomes greater, the flicker sensibility less. Third, the sensibility by the flicker method is less toward the ends of the spectrum, where the difference in hue between the spectrum color and the standard lamp color is greatest.

It is to be noted that while all the observers made readings



Figs. 2 and 3.—Errors of observers at illuminations of 10 and 250 units.

by the flicker method which compared very closely to the accuracy of those made by the two most experienced observers, two of the three by whom the settings were made for the first time averaged five or ten times the error by the equality-of-brightness method as by the other. This illustrates the great superiority of the flicker method as a method of measurement with observers not used to making matches between lights of widely different color.

Closely connected with the question of sensibility is the question of reproducibility at different times. Entirely satisfactory data on this point have not as yet been obtained, as it has been

found extremely difficult to separate changes in the color of the light source from possible changes in the luminosity criteria. It may be said, however, that flicker sensibility curves have been obtained on several successive days showing no changes larger than the range of error in the measurements, while the equality-of-brightness curves have shown marked changes. Further, since these experiments were begun the equality-of-brightness luminosity curves obtained by the writer have experienced a shifting over from the blue side to the red side of the flicker curve, while the changes occurring in the flicker curve are probably no greater than can be explained by changes in the tungsten lamp used as a source. A change of similar nature but in the opposite direction has also occurred with the writer's assistant, Mr. Luckiesh. It may, therefore, be said with confidence that the changes which occur from time to time in the results given by the two methods are less with the flicker than with the equality of brightness method, with the evidence in favor of their being very much less.

In connection with the question of sensibility may be given the data on the speeds used with the flicker photometer. As is well known, sensibility varies with the speed, being less at high speeds. In fact, with high enough speed all flicker vanishes, no matter what the differences in illumination from the two sources under comparison. In these experiments the speed was always adjusted to the lowest value at which flicker could be made to disappear. This was then read by means of an electric tachometer and reduced to cycles per second. In Fig. 4 are given the speeds as used by the different observers from end to end of the spectrum and for the two illuminations. The data show that much lower speed is necessary for low illuminations, and that the ends of the spectrum require higher speed than the middle. These facts readily fit in with knowledge derived from other sources and with such theory as we have of the action of the flicker photometer. The eye is more sensitive to flicker at high illumination than at low, hence the greater sensitiveness of the flicker method and the higher speed necessary at high illuminations. In order to compare lights of different colors it is necessary to attain such a speed that the color flicker, due to difference in hue, disappears. It is, therefore, to be expected

that the ends of the spectrum where the hue is most different from the comparison lamp, a higher speed is necessary, and with

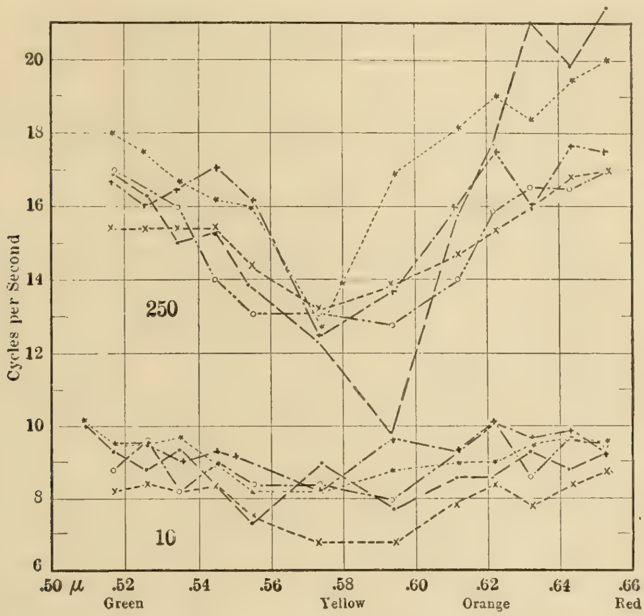


Fig. 4.—Frequency used by observers.

this higher speed goes decreased sensibility. Whether the change in sensibility is exactly what the change in speed would oc-

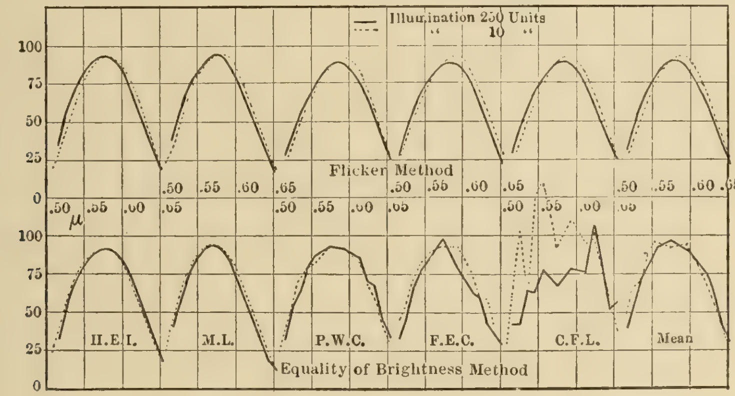


Fig. 5.—Effect of change in illumination on luminosity.

casion or whether the change in speed is conditioned by hue difference alone, are points for future study.

EFFECT OF CHANGING ILLUMINATION WITH EACH METHOD.

As to the effects of changing illumination on the luminosity curves; they may be described very briefly. They are illustrated in Fig. 5. With the equality-of-brightness method there occurs

a shift of the luminosity curve toward the blue end of the spectrum when the illumination is decreased. With the flicker method the shift is in the opposite direction. The shift by the equality-of-brightness method is the well known Purkinje effect. The shift in the opposite direction with the flicker method has not before been observed. It is of interest to note in this connection that the results obtained by changing the size of the field of view are also different for the two methods. It appears from the investigation now in progress that a decrease in the size of the photometric field increases the red sensitiveness in equality-of-brightness comparisons, but decreases it with flicker comparisons.

These two effects are perhaps due to the same cause—a change in the relative number of retinal rods and cones acting—and bear out the conclusion that the flicker method is affected in opposite manner to the equality of brightness method by these changes of the physiological conditions. This carries our knowledge of the relationship between the two methods a step beyond the conclusion which has been reached by some, that the flicker method merely responds less to changes in illumination or field size.

RELATIVE POSITION OF LUMINOSITY CURVES GIVEN BY EACH METHOD AT BOTH ILLUMINATIONS.

In Fig. 6 are given the equality-of-brightness and flicker luminosity curves directly as obtained, showing their relative positions. At the high illumination three observers show the flicker curve with its maximum on the red side of the equality-of-brightness, one with the maximum nearly agreeing in position and one with the maximum on the blue side of the equality-of-brightness curve. None of the observers show exact agreement at every point of the two curves, but the mean of all observers shows the two curves to have maxima very nearly at the same point. At the low illumination all the flicker curves fall to the red side of the equality-of-brightness curve, as is to be expected in view of the oppositely directed shifts of the two with change of illumination.

The data shown on this plate exhibit strikingly the more satisfactory nature of the flicker method, as far as definiteness is concerned and ease of making comparisons of this sort. While with

the more practiced observers the equality-of-brightness curves are comparable in smoothness with the flicker curves, with two of the less experienced the equality of brightness data are very unsatisfactory as curves. With one of the observers, in fact, it seemed next to impossible to form a decision as to a luminosity match between a bright spectrum color and the unsaturated color of the comparison lamp. This difficulty is reflected in the erratic character of the equality-of-brightness "curves."

An interesting point is that, in the case of some observers, the areas of the two curves (flicker and equality-of-brightness) are far from the same. If the total light is the sum of the separately measured parts it would follow that the total light is greater by one method than by the other. If, now, the spectrum used is

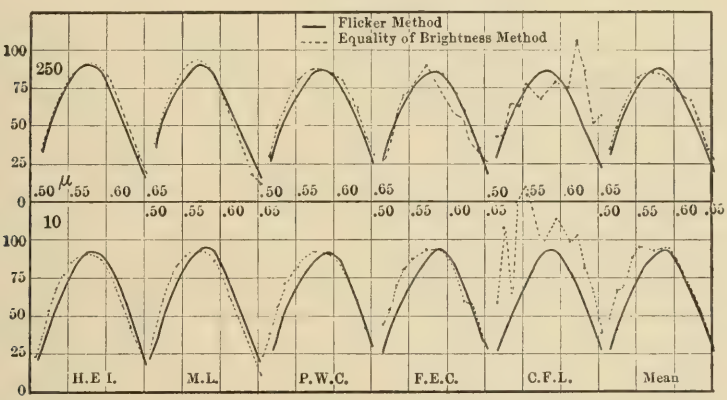
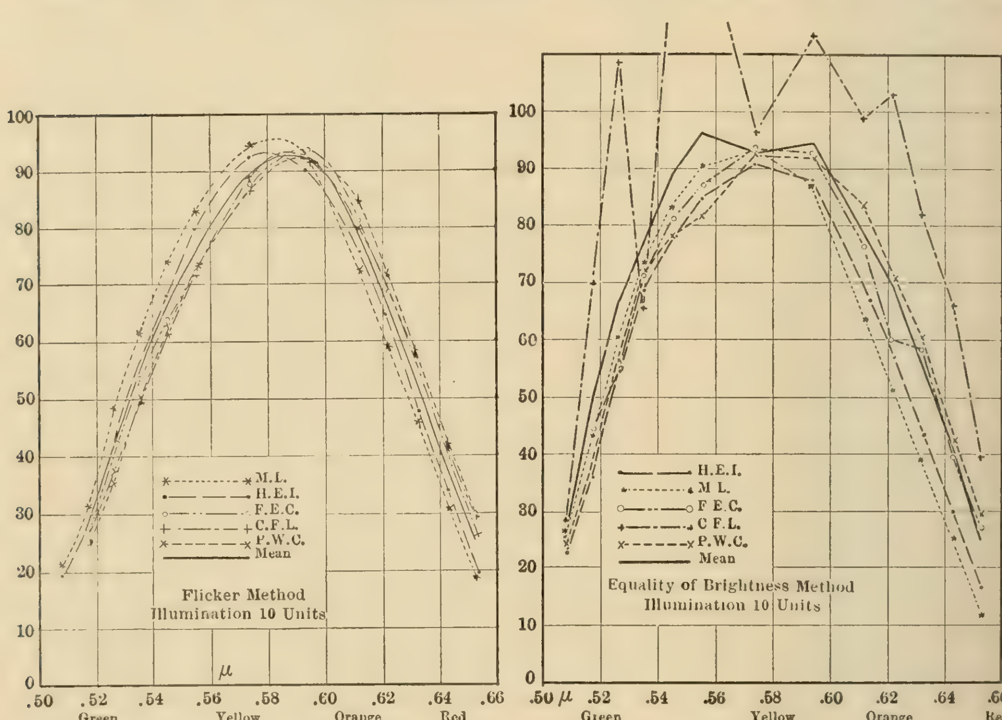


Fig. 6.—Comparison of equality of brightness and flicker methods at two illuminations.

of a lamp exactly like the standard lamp (used as comparison source) it is possible to recombine the dispersed spectrum and measure its total light against the exactly similar light of the comparison source. Under these conditions the total lights would measure the same by the flicker as by the equality-of-brightness method. This physical summation may agree with one or the other of the quantities obtained by arithmetically adding the luminosities of the component colors, but, in the case of the observers in question, cannot agree with both. This, then, offers one means of choosing between the methods, as methods of scientific measurement. Experiments on this point are now in progress.

RELATIVE POSITION OF LUMINOSITY CURVES DERIVED BY ALL OBSERVERS WITH THEIR MEAN VALUES

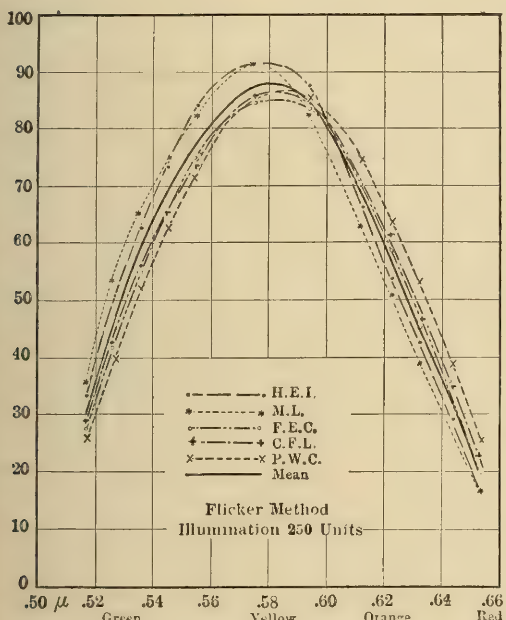
In Figs. 7, 8, 9, and 10 are shown the luminosity curves of all five observers together, for high and low illumination and both methods, with their means. These show that with observers of "normal color vision," that is, those who have no difficulty in making color matches or distinguishing colors, there exist considerable differences in the forms of the luminosity curves, both flicker and equality-of-brightness. For instance, if it were a

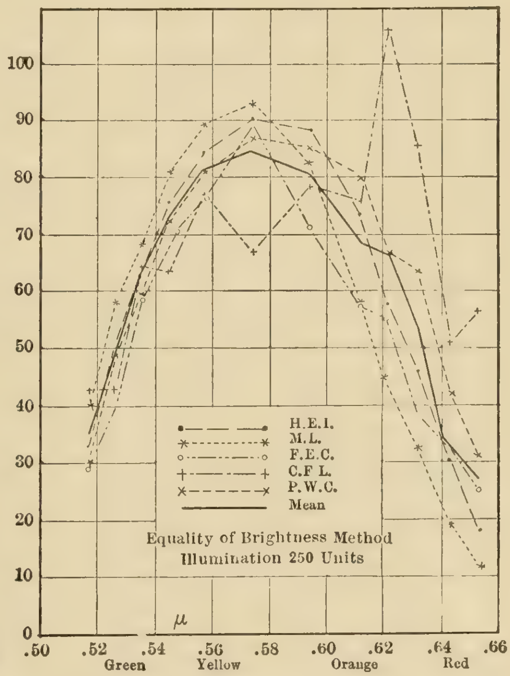


Figs. 7 and 8.—Luminosity curves for 10 units of illumination.

question of measuring a yellow-green at 0.55 μ against a 4-watt carbon lamp, the extreme observers would differ (by the flicker method at high illumination) by 15 per cent. Perhaps the preferable way to express the differences would be to compare the relative luminosities of the different spectral colors, thus eliminating the question of the character of the comparison lamp. This, however, would involve the assumption that the shape of these curves is independent of the color of the comparison light, and until this point is investigated, it is safer to state the results as obtained.

Inspection of the curves shows that the relative positions of the observers are substantially the same by both methods and illuminations, therefore apparently corresponding to real differences in color sensitiveness. These differences, as shown, are quite large, when pure colors are concerned. In the measurement of illuminants whose color is far less saturated than the colors of the spectrum, the differences between observers would not show so strikingly. Nevertheless is is evident that one can hardly expect any two observers taken at random to obtain ex-





Figs. 9 and 10.—Luminosity curves for 250 units of illumination.

actly the same results in heterochromatic comparisons if such differences in color sensitiveness are the rule, as there seems no reason to doubt. Hence it becomes evident that no matter which method of photometry is used dependence must be put upon the average results of numerous observers for the standard luminosity values of differently colored illuminants.

In Fig. 11 is given the spectral energy distribution of the source used. This was obtained by spectrophotometric comparison of the light as obtained through the prism, lenses, etc. of the instrument used, with that of the tungsten lamp matched against a black body at known temperature the distribution of energy

of which was calculated from the Wien equation. In the same illustration is given the mean high illumination flicker curve, reduced to a normal equal energy spectrum by taking into ac-

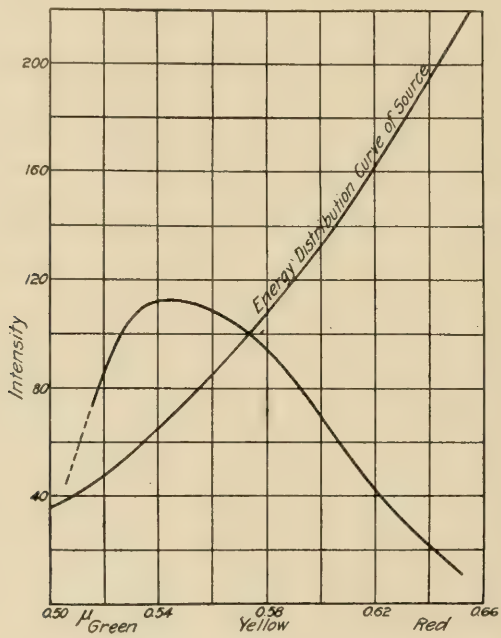


Fig. 11.—Spectral distribution of the light source.

count the distribution of energy in the source. It shows a maximum of luminosity at 0.545 μ.

SUMMARY AND CONCLUSION.

Spectral luminosity curves obtained by several observers using the flicker and equality-of-brightness methods do not show exact agreement between the two methods. With different observers the relative positions of the two kinds of curves are different. At low illuminations the equality-of-brightness curves shift toward the blue, the flicker toward the red. Marked differences in the color sensibility of the five observers exist, as shown by each method. The flicker method possesses much greater sensibility than the equality-of-brightness method, the difference being greatest at high illuminations.

The most important fact shown by this investigation is probably that the flicker method and the equality-of-brightness method give nearer the same values at high than at low illuminations. This result was thought probable before the investigation was

undertaken, from consideration of the results of other observers. There is some reason for believing the flicker photometer to act chiefly by means of those elements of the retina called the cones, in distinction from the rods. The cones are supposed to be responsible for vision at high illuminations, the rods at low. The Purkinje effect is ascribed to the shift from cone to rod action; it becomes very small at high illuminations. Furthermore, the flicker photometer had been found to show little or no Purkinje effect. It therefore seemed possible that at high illuminations, using a size of photometric field such that the retinal area used is very largely cones, the two methods might agree.

In view of the fact that the observers in this test placed the high illumination flicker curves some one side and some the other of the equality-of-brightness, it does not seem unwarranted to expect that with a large number of observers a still closer agreement between the mean flicker and mean equality-of-brightness curves might be obtained. In addition it might be remembered that, as stated above, an observer's equality-of-brightness criterion is apt to change from time to time with respect to his flicker criterion. In the writer's own case, at one time in the course of the investigation the equality-of-brightness and flicker curves agreed exactly for the size of field here used and an illumination slightly above this; at another time they agreed exactly at a slightly lower illumination. The uncertainty as to the real position of the equality-of-brightness points precludes determining definitely how they do stand with any one observer. Only by taking numerous observations under such conditions that the observer's memory of previous settings was lost could a true curve be obtained to compare with the easily-obtained and definite flicker curve. Therefore it may be said that while the observations shown exhibit clearly only the fact that the two curves approach each other at high illuminations, there is strong evidence that at the highest illumination here used (250 units) the mean of numerous flicker and equality-of-brightness curves would very nearly if not exactly coincide.

This then would be an argument for choosing such an illumination as the standard one for making the heterochromatic comparisons necessary for the preparation of standards of different

colors. For it must be clearly borne in mind that such comparisons can, from the nature of vision, hold exactly for only one illumination and size of field. The best solution to be hoped for must contain specifications of these two conditions. When the stage has been reached where one can give a definite candle-power rating to a colored illuminant for a certain illumination the first step will have been made. The second step will be when one can state also what the illuminant's candle-power will be at any other illumination, knowing it at the standard.

The much greater sensibility and ease of setting of the flicker method point to its decided superiority for heterochromatic photometry. However it is not the object of this paper to recommend the use of one photometer over another nor is any claim made that the results here given are in any way final. They constitute merely the preliminary steps in the investigation of the whole problem. Several important points must be investigated before the facts here brought out can be safely applied to practical photometry. Prominent among these lie the investigation of the effect of changing the color of the comparison source, and of the relative values of the physical and arithmetical summation of colored lights.

The above results show, however, as they stand several facts of scientific interest in the study of light measurement. These are expected to have important bearing on the further study of the practical side of the problem. They are given for that reason and, too, partly that the Illuminating Engineering Society may know that this problem in which it is prominently interested is being followed up.

The writer's thanks are due to Dr. P. W. Cobb, to Mr. F. E. Cady and to Dr. C. F. Lorenz for their kindness in making the readings here used, and especially to Mr. Matt Luckiesh, not only for assistance in the readings but for the preparation of the numerous drawings necessary to illustrate the paper.

DISCUSSION.

Mr. S. W. Ashe:—About three years ago at Columbia University, the speaker with others undertook an extensive investigation involving among other things the problem of color pho-

tometry. We spent 20 hours a week for one year on the problem. A considerable amount of work had been done there in the past by Prof. Rood, who was the father of the flicker photometer. The work was conducted in cooperation with the physics department and the department of psychology. Unfortunately the experiments were not entirely completed, but a great deal of pioneer work was done, and much of the investigation outlined has since been completed by others. Many of the points that we could not quite settle at the time have since been investigated. For instance, Mr. J. S. Dow in England carried on considerable work along the same lines and Mr. A. J. Sweet has also taken up certain other phases bearing on the acuity problem. Mr. P. S. Miller has also taken up the acuity end of it, and now Dr. Ives has taken up the flicker photometer. There are three methods of light comparison. One is the acuity method; another is the equality-of-brightness method, and the third is the flicker photometer method. Those who have attempted to compare lights by the acuity method realize that it is not at all satisfactory for commercial practice. Against the direct comparison method for color comparisons is the statements of Helmholtz, who was probably the greatest investigator the world has ever known on physiological objects, who said that he placed absolutely no confidence in his ability to determine equal luminosity of two different colors. On flicker work Dr. Rood probably did more than most other people. One of his convincing tests was to measure the individual intensities of two lights of complementary color on the flicker photometer. He then superimposed these lights over each other, producing white light, and the resultant intensity as measured on the flicker photometer was equal to the sum of the individual intensities of the previous colors. No one would want a stronger proof of the flicker method.

Some of the best work done with the flicker photometer has never been made public and never will be published, because the man who did it, Dr. Tufts, was accidently killed before the work was completed. The conviction is growing more and more as a result of various investigations that the flicker photometer gives a better answer than anything else to the question of the proper basis of color photometry. There is one point,

however, that has not been decided as yet, and that is what is actually measured by the flicker photometer. The fact that a slightly different answer is obtained with the same colored light sources when employing equality-of-brightness and the flicker methods leads to the belief that the phenomena in the two cases are different.

Many extravagant claims have been made for the flicker photometer and these claims have given photometrists a wrong impression of the instrument. For instance, in England use was made of color-blind subjects and many unwise claims were made; consequently there was a certain amount of prejudice at the beginning of our work which ourselves and others have had to discount.

Many things that Dr. Ives has mentioned agree with our results, such as the great sensibility of the instrument and the luminosity curves obtained.

Mr. G. C. Keech:—I should like to ask if any experiments have ever been made with sensitive plates.

Mr. F. J. Pearson:—About two years ago, the speaker working with others made several determinations on arc lamps, by means of the flicker photometer, using an incandescent lamp standard. In view of the fact that there were many variations in our reading, I ask Dr. Ives if in using a standard of low intensity such as a 16-c-p. incandescent lamp, a wide range of variation readings is to be expected. We failed to get concordant results all through the entire series of observations and I have always wondered why it was that such inaccurate results were obtained from the flicker photometer observation as checked with those from the Weber photometer using color screens.

Mr. R. C. Ware:—What is the effect of difference of speed at which the flickers rotate? Will not the balance be secured at different points as the speed is raised or lowered?

Dr. Ives:—One point to be emphasized in connection with the use of the photographic plate in its calibration. That is to say one must know how the eye estimates the brightness of colors in order to use anything else in the place of the eye, so that the first problem to be solved is the one of a method of photometry of lights of different colors. When this problem has been solved then it will be time to discuss using photographic

plates or instruments which measure radiation through a certain color screen, or the use of colored glasses or of secondary standards which will reduce the actual photometry to that of lights of the same color.

As to the question about the wide range of readings obtained by Mr. Pearson, I am at a loss to answer, because I do not understand what kind of range of readings he obtained; whether it was simply lack of sensibility or whether the readings at different times did not correspond. I should expect a greater definiteness and reproducibility with the flicker photometer. If the arc used was an alternating current lamp there would be a peculiar superposition of the flicker of the photometer with the flicker of the arc.

In regard to the difference in speed and the effect on the reading of the flicker photometer it may be said that there is simply one point at which the flicker photometer may be used for reading. If the flicker photometer is run fast enough, even when comparing light and darkness, one can set the photometer anywhere at all. If it is going about sixty cycles a second, all flicker can be eliminated. When two lights are being compared, the speed is much reduced. When it is not reduced enough, there is quite a space in the center of the photometer bar where the photometer head may be placed without flicker being noticeable. Beyond that space, there is flicker; by reducing the speed, the limits between which the photometer shows no flicker are reduced until a certain definite point is reached. The question of the effect of difference of speed simply drops out, for the reason that one cannot have different speeds when using the flicker photometer properly. There is only one correct speed.

Mr. P. S. Millar:—Does Dr. Ives advocate the use of the flicker photometer?

Dr. Ives:—I would recommend for the comparison of lights of different colors the use of no photometer. In other words, I think it extremely important—it is essential—that in ordinary photometry there should never be made a comparison of lights of different colors. All practical photometry should be reduced to the photometry of lights of the same color. Consequently, the question of which photometer is to be used for comparing lights of different colors, becomes a question for the standardizing laboratory, the Bureau of Standards the Reichsanstalt or

the National Physical Laboratory. I certainly do not wish to be understood as advocating the use of any particular kind of photometer in ordinary practice. When it comes to the question of methods to be used in standardizing laboratories, I do not think the work has gone far enough to warrant recommending one photometer over another. The object of the investigations reported is to determine ultimately what method can be used with the greatest success in the standardizing laboratory for securing secondary standards or colored glasses or other means by which practical photometry may always be the photometry of lights of the same color.

Dr. C. H. Sharp:—Does Dr. Ives want to make the statement that we ought to stop trying to compare lights which differ a little bit in color, simply for the reason that we cannot do it so precisely as we can lights of the same color? His last remark seems to imply that we must stop trying to photometer arc lamps, for example because we cannot do so as well as we can incandescent lamps.

President Hyde:—I do not want to presume to answer for Dr. Ives—let him answer for himself—but if I understood correctly Dr. Ives' view on the subject, it is this: There is no reason why there should not be established some standard methods for color differences, such that in the ordinary photometry of arc lamps against incandescent lamps or other lamps of different colors, there will be no need for measurement of the extreme color differences which occur. The establishment of a standard method is a problem that perhaps is up to the Research Committee of the Illuminating Engineering Society, (which has not yet been appointed), or is one which this committee should take up with the National Laboratory. The question of standardizing some method by which the color differences can be overcome will involve the photometric difficulties to which Dr. Ives has referred in his paper.

Dr. Ives:—The President clearly expressed my position. I think Dr. Sharp entirely misunderstood me on the point. I consider that the ideal towards which we should aim,—the goal in heterochromatic photometry,—is to reach the point where the practical observer never has to face the problem of comparing two lights of different colors. Such work should be done for him in the standardizing laboratory.

THE TEMPERATURE RISE DUE TO THE ENERGY RADIATED IN THE LOWER HEMISPHERE FROM DIFFERENT LIGHT SOURCES.[1]

BY J. G. FELTON AND E. J. BRADY.

The main problem that confronts the designer of a system of illumination is the broad and general one that calls for the efficient production and the proper distribution of a suitable light flux. This forms a positive proposition, but it involves a number of negative questions. Although the latter are of a minor nature, still they may be the deciding factors in the choice of a method of illumination. To illustrate the above point more clearly, one might conceive of an almost ideal source of illumination as far as the distribution of energy flow in the visible spectrum is concerned, with high efficiency, absence of heat and all the other desirable features of a light source, but if this same source gave off waves that could not be obstructed, and that were highly injurious from a physiological standpoint it would never emerge from the experimental laboratory and it would be necessary to use a less efficient but more practicable source of illumination. The case selected is of course, an extreme one, but where the decision in favor of any particular light source is close, the consideration of some of these negative questions may be sufficient to throw the decision the other way.

Among the factors that may determine the choice of a source of illumination there is one that, so far as the authors of this paper can determine, has never been investigated, namely, the relative temperature rise due to the "heat" radiated downward from commercial light sources.

The authors have recently done some work along the above lines, under the direction of Mr. Charles O. Bond, and believing that the results may be of interest to the engineering profession, and particularly to the illuminating engineers, have arranged some of the data for presentation to the Illuminating Engineering Society.

[1] A paper presented at the Fourth Annual Convention of the Illuminating Engineering Society, Baltimore, October 24 and 25, 1910.

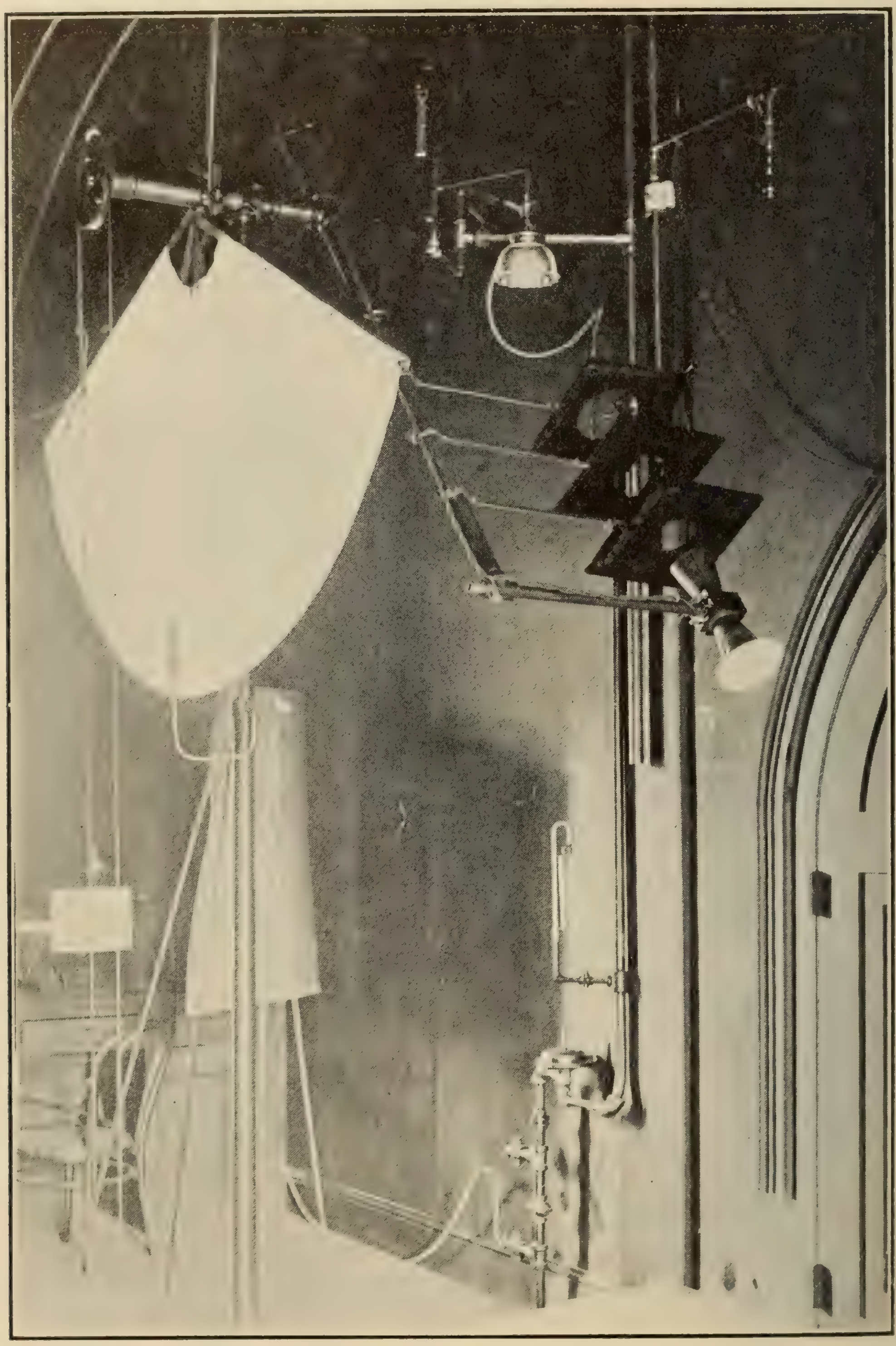


Fig. 1.—General view of testing apparatus.

In general, illumination is what a normal person perceives when light is intercepted by matter—the word light meaning the flow of radiant energy in a certain part of the spectrum. After the energy impinges upon matter and enters the eye, it leaves the province of present day physics and is no longer measurable in terms of energy, there being no known physical relation between illumination expressed in lumens per unit area and radiant energy

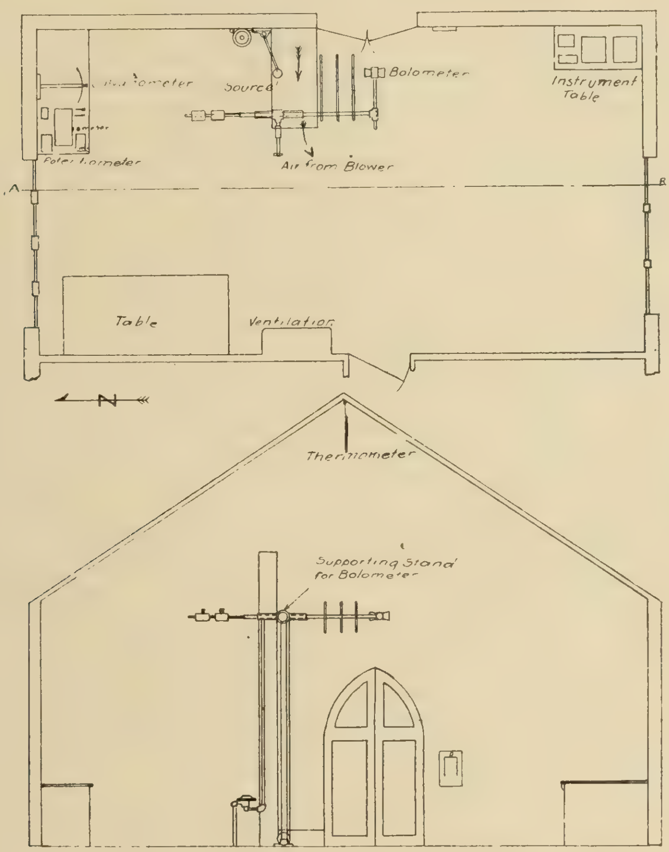


Fig. 2.—Plan and section of testing laboratory.

as expressed in calories. For this reason the authors have, to a certain extent, begged the above question regarding the relative temperature rise due to the "heat" radiated and entitled this paper: "The Temperature Rise due to the Energy Radiated in the Lower Hemisphere from Different Light Sources," meaning, of course, the total amount of radiated energy flow including both light and "heat." There are a number of methods by which the temperature rise due to the total radiation may be measured,

but the one finally adopted by the authors was by use of the bolometer, an instrument similar in principle to the one originally devised by Professor Langley during his researches in solar radiation.

In view of the fact that this instrument is not ordinarily used for commercial testing, and that the test here recorded is only the first of a series of investigations where it is hoped to establish quantitative relations, it is believed that a detailed account of it will not be out of place at this time.

The sensibility of the bolometer depends upon the fact that an increase in the temperature of a metal also increases the electrical

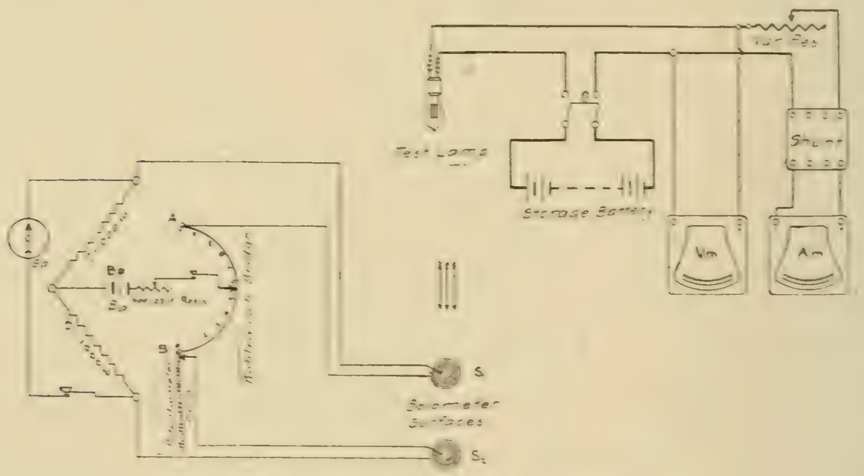


Fig. 3.—Diagram of testing apparatus.

resistance of that metal. As an extremely accurate means of measuring electrical resistance exists in the Wheatstone Bridge, it is necessary merely to place in one of its arms a surface so designed that a very small change in temperature produces a measurable change in its electrical resistance. The amount of this change in the resistance will vary directly as the temperature coefficient and the total resistance of the metal surface. The temperature coefficient of a metal is defined as the increase in resistance per ohm per degree centigrade rise in temperature and is expressed by the formula:

$$R_2 = \frac{R_1(1 - at_2)}{1 - at_1}$$

$$\text{or } R_2 - R_1 = R_1 a\left(t_2 - t_1\frac{R_2}{R_1}\right)$$

where $R_2—R_1$ is the increase in resistance due to the rise in temperature $t_2—t_1$, and a is the temperature coefficient of the metal.

It is seen therefore that in order to have $R_2—R_1$ measurable when $t_2—t_1$ is very small, R_1 and a must be as large as possible. For this reason the surface that was exposed to the radiation is made of nickel wire having a temperature-resistance coefficient of 0.0062 ohms per degree centigrade, and a total resistance of 1,200 ohms.

There are two other factors that the above formula does not bring out and that are very essential. In the first place the metallic surface upon which the radiation falls must be as thin as possible,

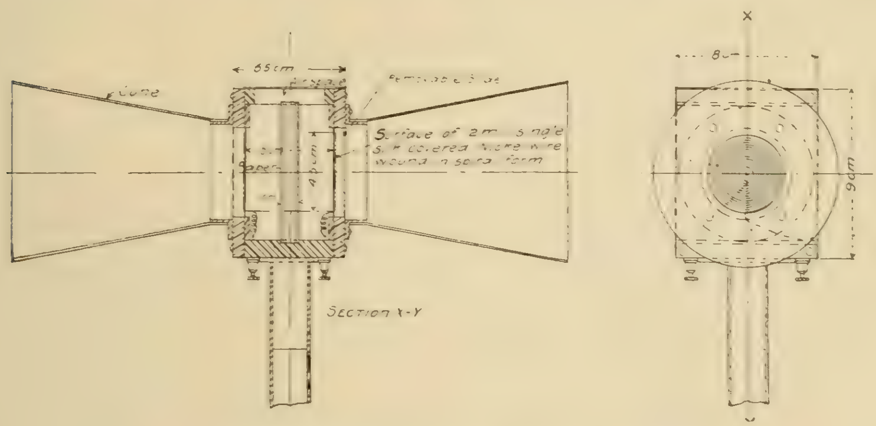


Fig. 4.—Longitudinal and transverse sections of bolometer.

otherwise it will take considerable time, owing to its thermal capacity, for the temperature of the surface to reach a state of equilibrium, and the instrument as a whole will have too much inertia, this being the principal objection to the thermopile; and, secondly, the surface should not be in contact with any substance that is a good conductor of heat.

The requisite qualities were secured in the instrument used by the authors by utilizing, in the main, the scheme of connections devised by the makers of the instrument.

An instrument with one coil in an arm of a bridge, as described, would be impracticable for obvious reasons. In fact the valuable part of Langley's invention consisted in bringing two of these surfaces with exactly the same resistance very close together, the two being placed in opposite arms of the bridge. In

this way both surfaces were at the same room temperature, and the rate of change of resistance due to changes in room temperature would be the same for each, and any difference in temperature would be due solely to the radiant energy falling upon the exposed surface.

The bolometer used by the authors is shown in Fig. 4. It is made of two spiral coils of single silk-covered nickel wire, two mils in diameter. Each coil is wound very close, the outside diameter being 4.5 cm. (1.8 in.) and it is then pasted to a very thin gauze stretched across the openings in the bolometer case. Across the case between the two surfaces, which are 5 cm. (2.0

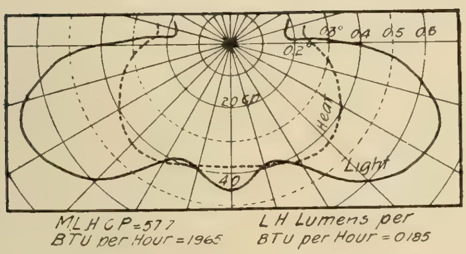
Figs. 5 and 6.—Upright mantle lamp with opal dome.

in.) apart, there is a partition of paper 1 cm. (0.394) thick to prevent the radiation from passing through and affecting the unexposed surface. Between each surface and the opening in the case which is 4.5 cm. (1.8 in.) there is a removable brass slide to protect the surface when not in use. The instrument is painted black, both inside and out. There is a conical hood placed upon each end to concentrate the rays upon the surfaces.

The bolometer is mounted upon an arm capable of being revolved around the test lamp in a vertical plane, the surface being 150 cm. (4.95 ft.) from the test lamp. This distance was kept constant for all the lamps. The whole apparatus, including the bolometer and connecting wires, with screens, and graduated sector, is shown in Fig. 1.

Fig. 3 shows a sketch of the bolometer and test lamp connections. The Wheatstone bridge connections, of which the bolometer surfaces form two arms, are shown on the left. In the arm with the unexposed surface is placed only that part of a potentiometer circuit that contains the 15 five-ohm coils and a slide wire bridge of the Kohlrausch type, having a resistance of 5.5 ohms.

When the coil S_1 would change in resistance due to the radiation, to preserve the balance of the bridge it would be necessary to slide the contact point towards the S_1 arm and when this new balance would be established, the increase in resistance of S_1



Figs. 7 and 8.—Upright mantle lamp with opal shade.

would be equal to twice the resistance passed over by the contact point.

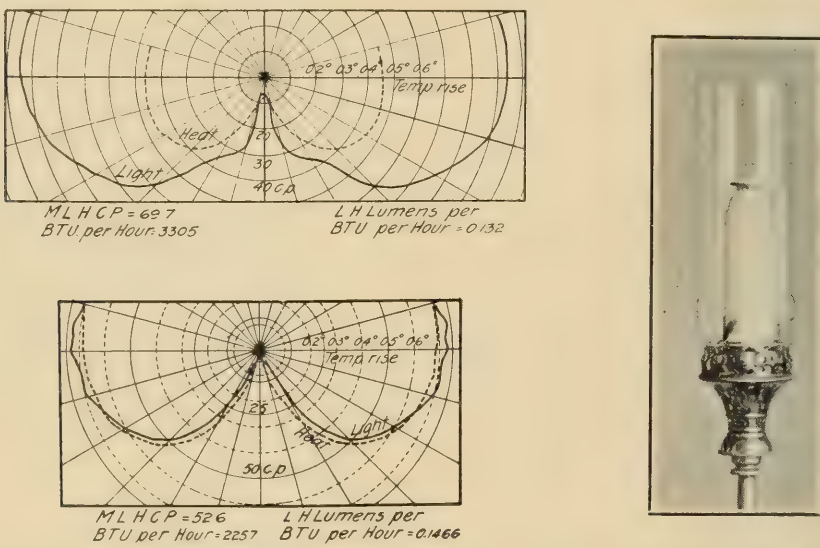
If the radiation was sufficient to necessitate sliding the contact point to the end of the slide wire, the point would be run back five turns and one of the 5-ohm coils would be inserted. At no time was it necessary to insert more than three of the 5-ohm coils.

The slide wire had 2,200 graduations, and by interpolating to one-fifth of a graduation it was possible to measure the increase in resistance to 0.0005 ohm. With the bolometer coils used, this change in resistance corresponds to a change in temperature of less than 0.0001 degree centigrade. On the whole this sensibility was reduced one-half, owing to the relative insensibility of the galvanometer which was of the D'Arsonval wall type. It is

very important that the four wires leading to the bolometer coils be twisted so that air currents will affect all of them equally.

To give one an idea of the degree of sensibility of the instrument, a lighted candle placed ten feet from the surface would cause the galvanometer to read ten or twelve divisions. This is not very sensitive, as anyone that understands the possibilities of the bolometer will readily see, but it proved to be sufficiently sensitive for our purpose.

To test the reliability of the instrument a test was made with one of the electrical standards, beginning at 0° and passing up to 104°, then returning and reading the same angles, the voltage

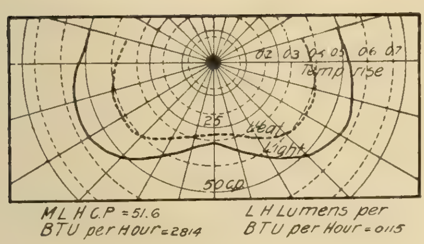


Figs. 9, 9A and 10.—Upright mantle lamp with and without chimney; no reflector.

of the lamp being kept constant all the while. The difference in the two readings were, on the average, so small that they could be attributed to experimental error.

To determine the effect of the radiation from the ceiling and walls, the bolometer was rotated through 180° without any lamp in position and a series of readings was made. To insure normal conditions during this test a lamp liberating 3,100 B. t. u. per hour was kept burning in a sheet-iron casing on the opposite side of the room, none of the radiation from the casing reaching the bolometer surface. Owing to the screens on the bolometer arm, the intensity of the radiation as received from the wall should be independent of the distance and depend entirely upon the tem-

perature of the wall. This test showed that the radiation from the ceiling was a little greater than that from the wall at the height of the bolometer, but the difference was so small that it



Figs. 11 and 12.—Upright mantle lamp with opal globe.

did not justify correcting each heat ordinate on the curve shown.

Two thermometers, indicating to tenths, were read before and after each run, the upper one being hung near the roof, as shown

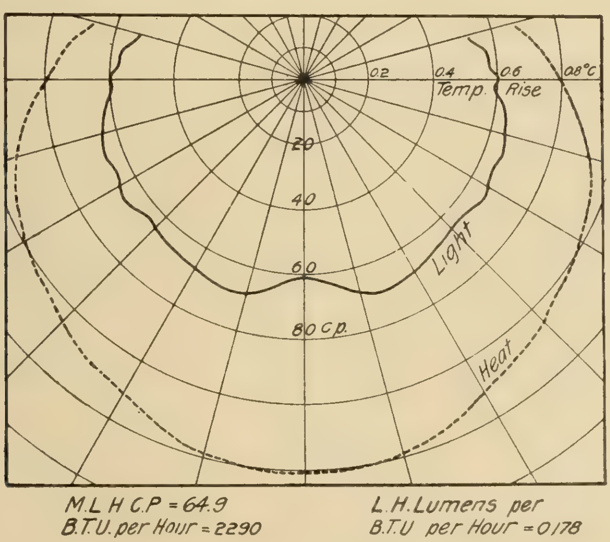
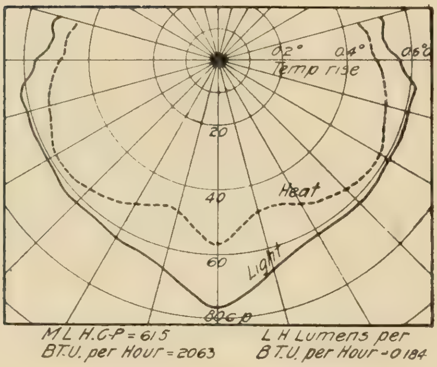


Fig. 13A.—Inverted lamp with bare mantle

in Fig. 2, and the other one being 1.5 m. (5 ft.) above the floor near the bolometer stand, as shown in Fig. 1. The average of these differences between the upper and lower readings was 4.67° C. This difference is higher than it would be with a horizontal

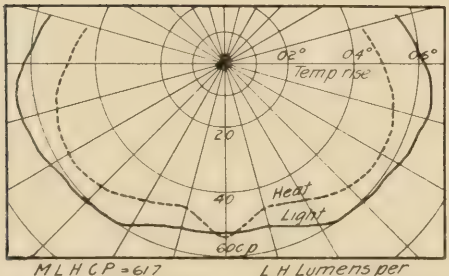
ceiling, the gable roof having a tendency to concentrate the heat in the peak.

In Fig. 2 the arrangement of the bolometer room is shown



Figs. 13 and 14.—Inverted mantle lamp with clear cylinder; no reflector.

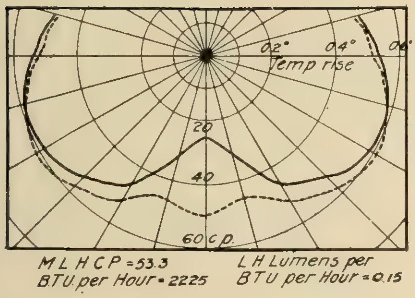
drawn to scale. The North, South and East walls are of stone, 45.7 cm. (18 in.) thick, and on the West there is a lath and plaster partition. The windows on both ends are double glass with a

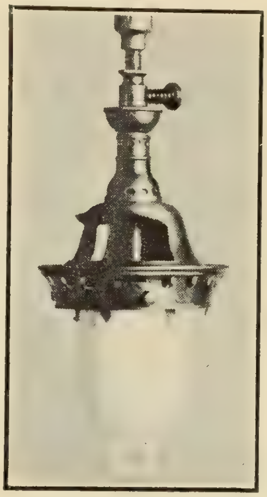


Figs. 15 and 16.—Inverted mantle lamp with half-frosted cylinder; no reflector.

15 cm. (6 in.) air space, the inside one being painted black. This insures that there were no downward convection currents near the windows. Proper ventilation was provided by a blower

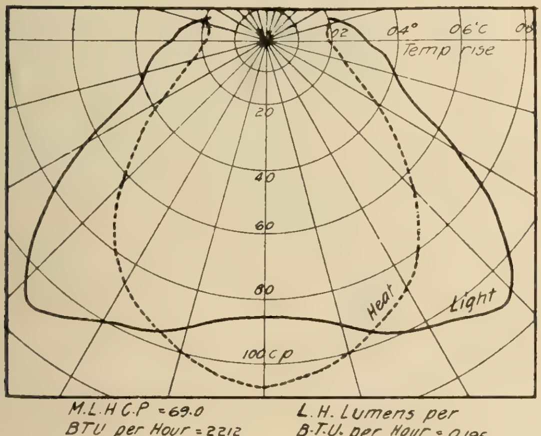
which forced air into the room at the bottom and out at the top, the supply as shown by anemometer readings being at the rate of 4,280 l per min. (9,066 cu. ft. per hour) thus changing the





Figs. 17 and 18.—Inverted mantle lamp with opal cylinder; no reflector.

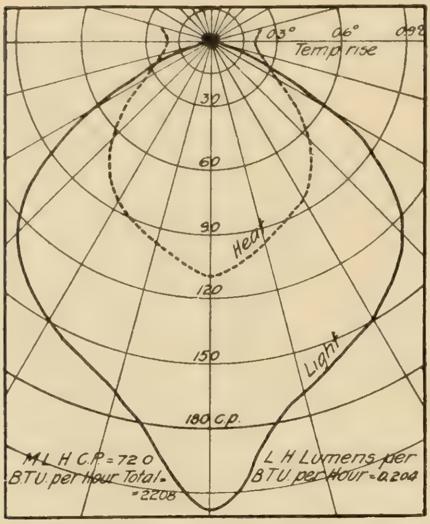
air in the room every thirty-eight minutes. The inlet was so placed that the bolometer and test lamp were out of the path of any direct drafts.

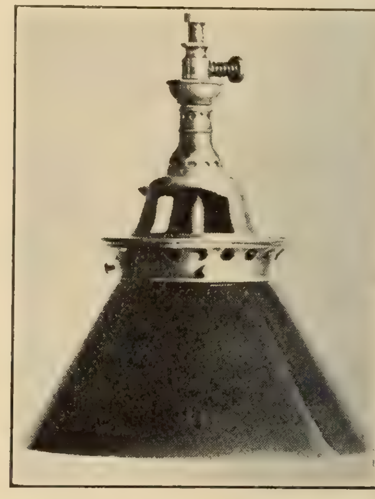


Figs. 19 and 20.—Inverted mantle lamp with half-frosted cylinder; clear prismatic reflector.

The method of testing was as follows: A lamp was put in condition and allowed to run for one-half hour. This insured the lamp unit being thoroughly warmed up. Mixed gas at a

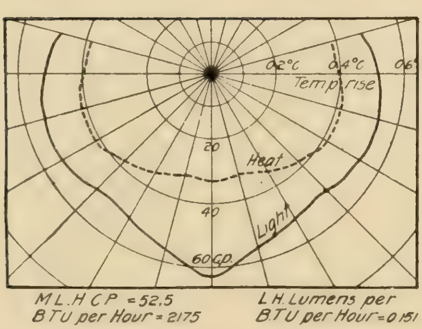
constant pressure of two inches of water was used on all gas lamps. After this heating up, the light distribution curve in a vertical plane was obtained, during which the consumption of





Figs. 21 and 22.—Inverted mantle lamp with half-frosted cylinder; green cone shade.

gas corrected for barometer and temperature, were ascertained. A record was also kept of the hygrometric condition of the air. After this the lamp was hung in place in the bolometer room

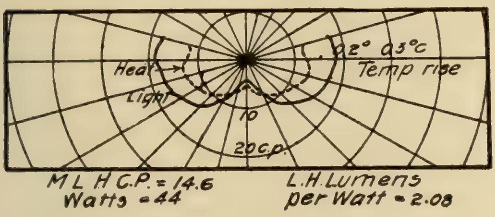


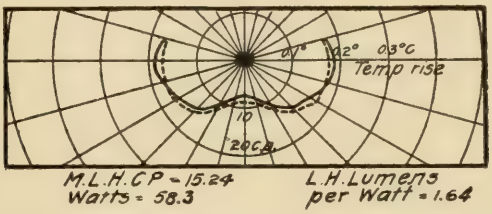
Figs. 23 and 24.—Inverted mantle lamps with frosted-tip cylinder; Austrian opal globe.

and operated under exactly similar conditions. Here the bolometer was rotated around it and the "heat" distribution curve in the lower hemisphere was obtained. The bolometer readings

started at nadir and ascended to 90°, by the ten-equal-zone method.

Before beginning the readings the bolometer was shielded from all radiation and left in the nadir position until both surfaces were at the same temperature, when an equilibrium read-



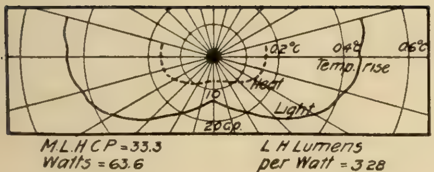


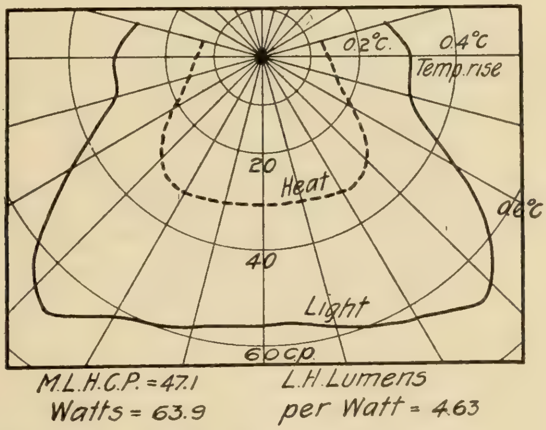
Figs. 25 and 26.—Tantalum and carbon filament lamps.

ing was made. This reading was regarded as the zero for that particular run.

All of the electric lamps were operated at 110 volts from a storage battery and treated similarly to the gas lamps.

Some of the results of applying the above tests to the different lamps are very interesting. For example, in Fig. 5, there is



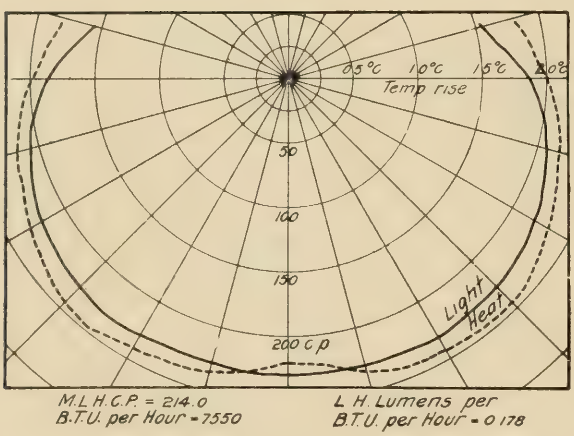


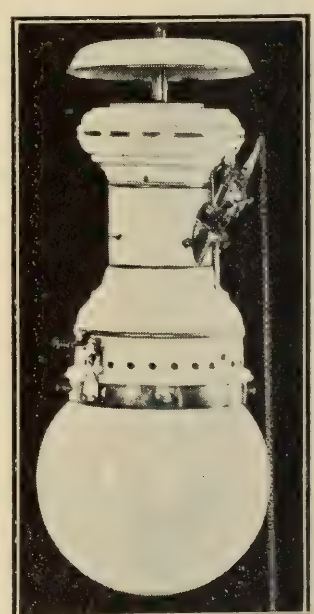
Figs. 27 and 28.—Bowl frosted Tungsten filament lamp without and with prismatic reflector.

shown the curves of the lamp illustrated in Fig. 6, which gives 99.7 mean lower hemispherical candle-power. Both the temperature rise and the candle-power curves bear about the same ratio to one another at all the angles except zero. This is as one might expect. In Fig. 7 are given the curves of the lamp shown in Fig. 8, having a mean lower hemispherical candle-power of 57.7, which is similar in construction to the lamp shown in Fig. 6, the only

difference being in the size of the mantle and the shape of the shades, both being opal. Here the temperature rise curve has the same shape as before, except at zero, while the light curve varies greatly as shown, there being apparently no relation between them. The lamp in Fig. 6 gives off 1.73 times as much light in the lower hemisphere, while the temperature rise on the 18° angle is only 1.25 times as great as the one in Fig. 8, there being a smaller difference in their efficiency than one might expect.

In Fig. 9a, are given the curves of a bare upright mantle





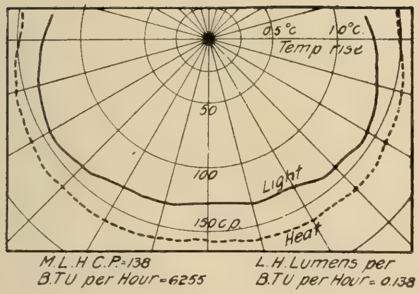
Figs. 29 and 30.—Four burner inverted-mantle cluster lamp with Austrian opal globe.

with no chimney while Fig. 9 shows the effect of placing a clear glass chimney on this lamp. The chimney increases the mean lower hemispherical candle-power by 32 per cent., and decreases the efficiency in the lower hemisphere by 10 per cent. The decrease in efficiency was caused by the greatly increased consumption in the latter case, and by the redistribution of the light, part being transferred to the upper hemisphere.

Fig. 25 shows the curves of a 40-watt tantalum lamp with no shade, the improvement over the plain carbon, the curves of which are shown in Fig. 26, being very noticeable, but the 60-watt tungsten is as much of an improvement over the tantalum

as the latter is over the plain carbon, as can be seen by a comparison of the curves in Figs. 25 and 27. The curve of a 60-watt tungsten with a prismatic reflector is shown in Fig. 28. It is to be observed that with all the electric lamps the general form of the temperature rise curve is very similar to the light curve, and this relation exists even with the prismatic reflector. Such is not the case, however, with the gas lamps as can be seen by referring to the curves of an upright mantle lamp in Fig. 19. Here the variation of the temperature rise seems to bear no relation to the variation of the light.

Figs. 13 to 24, inclusive, are the curves and photographs of



Figs. 31 and 32.—Three-burner inverted mantle cluster lamp with ordinary opal globe.

the inverted type of gas lamps, with various accessories. Inverted lamps obviously radiate the most energy in the lower hemisphere, and it is this type of lamp that one would expect to be objectionable; but an examination of the curves will show that candle for candle, they compare very favorably with the upright lamps, (Fig. 6), and also with the tungsten lamps, having a prismatic reflector, (Fig. 28), as will be seen by referring to the curves in Fig. 33, which will be explained subsequently. This relation is especially true of the inverted gas lamp with

an Austrian opal ball globe and also the inverted lamp with a green cone shade.

Fig. 13 shows the distribution of light and heat for an inverted mantle lamp equipped with a clear cylinder, as shown in Fig. 14. A comparison of these curves with those shown in Fig. 13a, which are for the same lamp except that the mantle was bare, will show the effect of the opacity of the glass cylinder to certain radiations of long wave lengths. It will be observed that the mean lower hemispherical candle-power in the two cases is about the same, but that the mean temperature

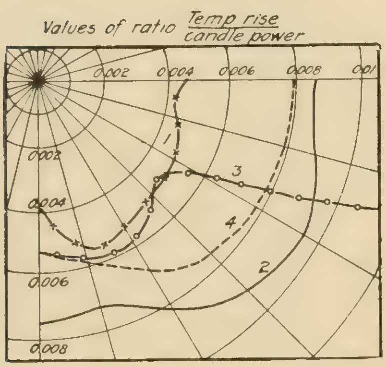


Fig. 33.—Mantle gas lamps.

(1) Upright, with opal dome, (Fig. 5).
(2) Inverted, with clear cylinder, (Fig. 13).
(3) Inverted, with green cone shade, (Fig. 21).
(4) Inverted, with Austrian opal globe, (Fig. 23).

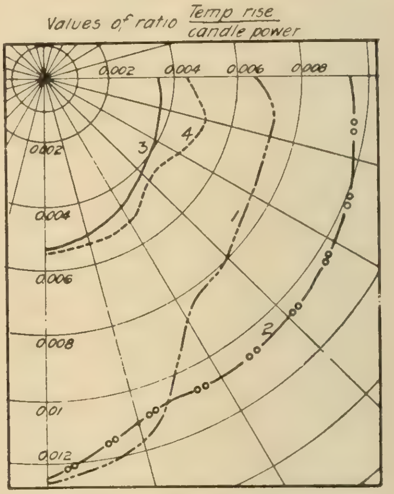


Fig. 34.—Filament electric lamps.

(1) 40—Watt tantalum, no reflector (Fig. 25)
(2) 58—Watt carbon, no reflector (Fig 26).
(3) 60—Watt tungsten, no reflector (Fig. 27).
(4) 60—Watt tungsten bowl frosted prismatic reflector (Fig. 28).

rise in Fig. 13a is 83 per cent. greater than that in Fig. 13. This fact shows the desirability of using glassware over incandescent mantles.

Fig. 15 shows the effect of using a half-frosted cylinder and Fig. 17 the effect of an opal cylinder. In the former the ratio of the light to heat is changed very little, as compared to a clear cylinder, except at zero, where the frosted glass naturally reduces the light; however, the opal cylinder, due to its diffusing properties, reduces the light rays and apparently has little effect on the heat rays.

Fig. 19 gives the curves for the prismatic reflector equipment shown in Fig. 20, to which reference will be made later. Fig. 21 gives the curves for the green cone reflector, shown in Fig. 22. Here the desired effect of a large increase of light over heat at the nadir position is realized. The same is true in Fig. 23, which are the curves for the Austrian opal ball globe equipment shown in Fig. 24. While such a light distribution is not ideal, yet such a relation of light to total energy approaches the ideal as far as the consumer is concerned.

In Fig. 29 are given the curves of the lamp shown in Fig. 30,

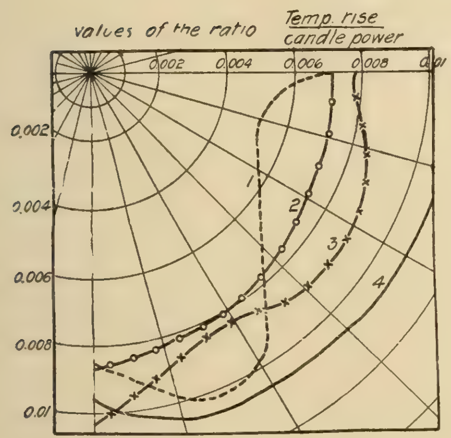


Fig. 35.—Mantle gas lamps.

(1) Upright, with opal shade (Fig. 7).
(2) Upright, with opal globe (Fig. 11).
(3) Inverted, with half-frosted cylinder. (Fig. 19).
(4) Inverted 4-burner cluster. (Fig. 29)

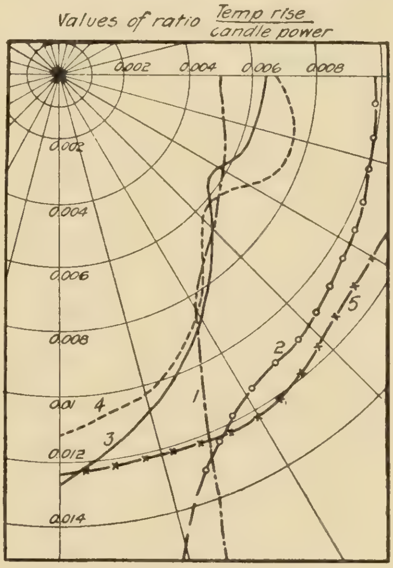


Fig. 36.—Mantle gas lamps.

(1) Upright, no reflector (Fig. 9).
(2) Inverted, with opal cylinder (Fig. 17)
(3) Inverted, clear prismatic reflector (Fig. 19).
(4) Inverted, satin finish prismatic reflector.
(5) Inverted 3 burner cluster (Fig. 31).

having four burners and an Austrian opal globe. The uniformity of the curves is noticeable. This may be compared with a three-burner lamp, with an ordinary opal globe, the curves of which are shown in Fig. 31, the lamp itself being illustrated in Fig. 32.

The curves from Fig. 5 to Fig. 31, inclusive, show the relative temperature rise in the lower hemisphere for the different lamps considered, but the mean lower hemispherical candle-pow-

er varies so greatly that a direct comparison is rather difficult. If a lamp giving, say, 50 mean lower hemispherical candle-power placed above ones head proves objectionable, the question that naturally arises is whether the heat is due to some defect that is peculiar to the lamp, or is due in whole or in part to the increased candle-power. To bring out this point and to reduce all the light values to a common basis, the curves have been plotted as shown in Fig. 33 to 36, inclusive. These curves are perhaps the most interesting part of the investigation. As

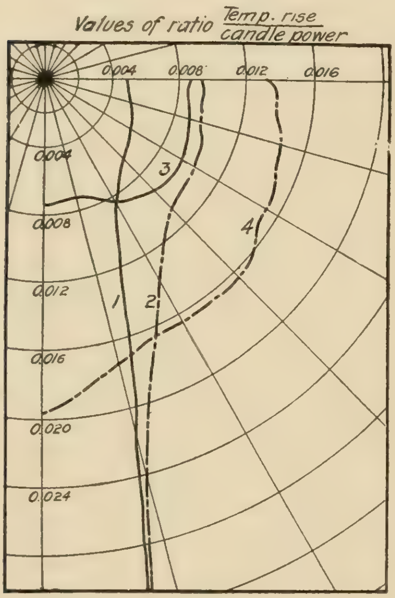


Fig. 36A.—Mantle gas lamps.

(1) Upright, no reflector (Fig. 9).
(2) Upright, without chimney (Fig. 9A).
(3) Inverted, with clear cylinder (Fig. 13).
(4) Inverted, bare mantle (Fig. 13A).

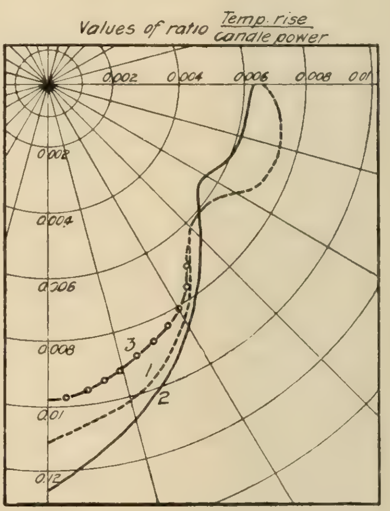


Fig. 37.—Inverted mantle gas lamps.

(1) Satin finish prismatic reflector.
(2) Clear prismatic reflector.
(3) Satin finish prismatic reflector with Austrian opal plate.

will be seen, they show the values of the ratio (temperature rise) ÷ (candle-power) and are plotted for different angles in the lower hemisphere. It is to be observed that this is purely a fictitious quantity, having no meaning from a physical standpoint, although it very clearly represents the relation to be brought out. It not only reduces the lamps considered to a common basis, but it does so on each particular angle in the lower hemisphere. Fig. 33 gives the value of this ratio for the lamps as noted on the curves. The upright gas lamp (Fig. 6), with the opal dome, gives the lowest value at zero. This fact means that

candle for candle this lamp raises the temperature of a black surface placed beneath it less than any of the other lamps investigated, not excepting the bare tungsten lamp while a comparison with a tungsten lamp having a prismatic reflector, shows that the latters' temperature rise per candle exceeds that of the upright gas lamp for a distance of 20° on each side of the vertical.

The next in order are the two lamps shown in Fig. 22 and Fig. 24. For these lamps the value of the ratio on the zero position is respectively 0.00529 and 0.00527, being about the same as that of the 60-watt tungsten lamp, with and without a prismatic reflector, namely, 0.00544 and 0.00532, respectively. Placing the prismatic reflector on the tungsten lamp changes the ratio very little at zero, although it does change it at the higher angles. It is to be observed when comparing the best of the electric lamps with the best of the gas lamps that, with the former the value of the ratio is least at the horizontal and greatest underneath, while the reverse is true of the gas lamps, that is, the ratio is least beneath the lamp and greatest at the horizontal. The values of the ratio for the four gas lamps as shown in Fig. 35, are not to be compared with those on Fig. 33, but they compare favorably with those of the tantalum and plain carbon lamps shown on Fig. 34.

Fig. 36 gives the ratio for a number of gas lamps as shown. They resemble somewhat the electric lamps in that the ratio is greatest underneath and least at the horizontal.

One of the most notable results of the test is the effect of the Austrian opal globe on the temperature rise. Returning to Figs. 17 and 23, the curves of the lamps shown in Figs. 18 and 24, respectively are shown. These two lamps are almost identical, there being very little difference in the mean lower hemispherical candle-power, efficiency, consumption or in the liters of moisture per cubic meter, the only difference being in the globes; the lamp of Fig. 17 has an ordinary opal cylinder and that of Fig. 23 an Austrian opal globe, and yet the temperature rise curve of the latter at zero is only 66 per cent. of the former on the same angle. The temperature rise curve and the light curve are interchanged at nearly all the angles. To verify this result curves were taken first of an inverted gas mantle lamp with a clear

prismatic reflector, then with a satin finish prismatic reflector and finally with a satin finish prismatic reflector having an Austrian opal plate placed underneath the cylinder (half frosted). The changes that took place in the value of the ratio are shown in Fig. 37. The change, of course reduced the mean lower hemispherical candle-power considerably, but it reduced the temperature rise in a much larger ratio.

The above is only one of the several very interesting facts that the test brought out, and the authors believe that it opens up a very large field of investigation for the manufacturer of lighting appliances. Of course the bolometric methods of comparing the heat-transmitting or heat-absorbing qualities of lighting accessories is not to be compared with a spectroscopic method, whereby the whole spectrum is analyzed, but it has certain advantages in that it is more simple and that it sums up the total effect over the whole spectrum as received from the light source.

DISCUSSION.

Mr. W. A. Dorey:—Among the factors that may determine the choice of a source of illumination is the question of the relative temperature rise due to the "heat" radiated downward from commercial light sources. However, nothing is said as to whether the authors think that this is a question that should determine the choice of an illuminant. It does not seem to me that the results given would warrant anybody choosing any one of the particular forms of illuminant on account of the proportion of radiant energy in the lower hemisphere. Do the authors think that the results warrant such a choice?

Dr. H. E. Ives:—There is one test which apparently has not been made, which I should think would be of extreme interest, that is, the comparison of incandescent lamps with clear bulbs and with frosted bulbs. Looking at it from the theoretical standpoint, the diffusion which is due to the frosting becomes less the longer the wave length; that is, in the infra-red, the heat region, I should expect less diffusion, perhaps much less than in the visible region. It might therefore result that the most characteristic curves of this type would be those found in comparing a clear bulb incandescent lamp with a frosted bulb lamp.

Dr. C. H. Sharp:—I wish to express my admiration for the work accomplished by the authors. The bolometer is essentially a particularly difficult contrivance to use, and to put it into use successfully in a piece of work as the authors have done is a most commendable thing.

There are two points to which I should like to call attention to. From a conclusion which is derived in some way unknown to myself, the authors think that the resistance of the bolometer arm should be as large as possible. That is a statement which must be accepted with very great reservation. The ratio of the change in resistance per degree of rise in temperature,—in other words, the temperature-resistance coefficient—is the most important feature, and for other reasons, the actual resistance of the bolometer arm should be of convenient value, not too small and not too large, but should not necessarily be as large as possible. The statement of the temperature coefficient is made in terms of ohms per degree centigrade, which if it means temperature coefficient in the ordinary sense, indicates a very high one. If it means the temperature coefficient on a total resistance of 1,200 ohms, it is very low.

I think it is rather unusual fr a bolometer to have a silk covered wire. In the ordinary form use is made of very thin strips blackened carefully, so that the heat is dissipated at once. Moreover, I do not think it is usually true that the surface should not come in contact with any substance that is a good conductor of heat. If a bolometer surface is in contact with a poor conductor of heat and is exposed to radiation, this surface will gradually become warm, the heat "soaking" in and changing the zero of the instrument.

The measurements recorded probably take no account of the fact that, in using gas lamps, the upper part of the room and ceiling become heated by the hot gases which rise and radiate heat to the lower parts of the room; whereas, with the electric lamp, the small amount of heat produced causes this effect to be considerably lower. There is no reason to expect that a mantle burner should of itself radiate very much more heat than an incandescent lamp of the same candle-power, but it gives off more heat by convection, and some of the heat is returned to the

lower part of the room by radiation. This factor in a practical case cannot be lost sight of.

Mr. Norman Macbeth:—A point of particular interest to gas men brought out in this paper is that the radiant heat from a mantle burner when used without glass is 83 per cent. greater than when the burner is equipped with glass. That is a point which should be of particular value in discussing gasoline installations. This point will also be of interest to some of our electric friends who are troubled with gasoline competition.

As Dr. Sharp brought out, a considerable amount of heat is carried off by convection in the air currents from a gas lamp. Much depends of course on the height of the ceiling and the ventilation at the ceiling as to just what the result would be in additional radiation into the lower part of the room.

The tests here reported are very important. It is especially interesting to note the difference in the radiant heat in the lower hemisphere with the lamp equipped with Austrian glass. That glass is an especially good diffuser of light and is consequently a very satisfactory glass from the illuminating engineering standpoint. The tests reported where a small disc of this glass was placed in the bottom of the cylinder give promise that we may some day have a heat-less gas lamp.

It is very easy to determine the total amount of heat both radiated and convected, given off either by a gas lamp or an incandescent electric lamp, from the fact that there are 3,410 B. t. u's per kw-hour; gas has at an average of say 600 B. t. u.'s per cubic foot with hard coal at approximately 14,000 B. t. u.'s per pound. The facts are then, that for an equal effective illumination there is twice the total heat from a gas lamp that there is from a carbon filament lamp; there is ten times the heat from an open flame as from a carbon filament lamp or five times in the open flame what there is from the mantle burner. The amount of heat liberated by the ordinary gas lamp consuming approximately 3.5 cubic feet of gas per hour, is equivalent to a cube of hard coal 1.5 inches square the combustion of which is prolonged over one hour. One would not attempt to heat a room with a small cube of coal like that suspended six or seven feet from the floor and yet some say that a room can be heated most wonderfully with a gas lamp.

Mr. Ward Harrison:—In Mr. Macbeth's figures relative to the carbon incandescent lamp and the vertical gas mantle lamps, I believe the comparisons are based on the horizontal candle-power of the gas lamp and on the mean spherical candle-power of the carbon lamp, and the assumption is made that the latter lamp is operating at about four watts per candle, which I do not think is the standard consumption of carbon lamps at the present time.

Mr. Brady:—In regard to Dr. Ives' question about the effect that frosted bulbs might have upon the shape of the curves, we have not had time to apply this test to a very large variety of lamps, and possibly there may be something in his question. One might infer what the effect would be from the curves of the gas lamps having half-frosted cylinders.

As to Dr. Sharp's criticism of our use of the words "as large as possible," in describing the bolometer, I agree with him; the use of those words was rather unfortunate. But as to his question about having the bolometer in contact with a conductor of heat, I do not agree with him on that point. As a matter of fact the bolometer should be in a vacuum to eliminate the conductivity of the air.

There are a number of conclusions that one may come to after studying the curves in the paper. It remains to be found out why the curves take the particular shapes that they do; I think our attitude on this point is expressed in the paper. It remains for future investigation to determine just why the curves take particular shapes under slightly different conditions.

Dr. W. W. Coblentz (by letter):—The radiometric investigation of the energy radiated from various illuminants is not of recent date. In connection with the results reported, the investigations of Lux (*Z. S. für Beleuchtungswesen*, 1907, Heft 16 n. ff) and of Leimbach (*Zeitschrift für Wiss. Photographie* 8, p. 333, 1910) are of great interest. The very different appearance of the "light" and the "heat" curves, as found by the aforesaid experimenters is not so very unusual if one considers the various factors entering into the measurements. For example, in the bunsen flame most of the energy radiated is concentrated in a large emission band of CO_2 at 4.4 μ. The incandescent mantle, contrary to our usual ideas of radiation from solids, emits but

little infra-red radiation as compared with the amount of light emitted. The combination of these two radiants, oxide mantle and hot gas, forms the ordinary gas light. Now glass is opaque to the radiation of the bunsen flame, (CO_2 band at 4.4 μ) hence the part transmitted by an opal globe, (Figs. 13, 31, etc.,) or a glass chimney is of the same quality as the "light" emitted. On the other hand, when no glass intervenes between the gas mantle and the bolometer, as appears to be the case represented in Figs. 19 and 20, the strong emission band of CO_2 is not absorbed and hence impinges on the bolometer when exploring the lower hemisphere. Consequently the bolometer is heated to a higher temperature than it would be if a glass screen intervened. Since the intensity of the emission varies with the thickness of the radiating layer of the hot gases while the "light" emitted is not related to the thickness of the radiating layer of the bunsen flame, being dependent upon the mantle, the "heat" curve will assume an entirely different form from the "light" curve, as shown in Fig. 19.

In the metal filament lamps most of the radiation lies in the spectral region where glass is transparent, and since it is always present anyway, it is apparent that the "light" and the "heat" curves should be very similar.

REPORT OF PROGRESS ON FLAME STANDARDS.[1]

BY E. B. ROSA AND E. C. CRITTENDEN.

The most successful primary flame standards used in photometry are the Hefner amyl acetate lamp and the Harcourt 10-c-p. pentane lamp. The former is especially favored in Germany, and is the official standard recognized by the Physikalisch-Technische Reichsanstalt. The latter is preferred in England, and is the official standard of the London Gas Referees and the National Physical Laboratory. Both are used in America, and have been studied and certified at the Bureau of Standards, although neither has been officially adopted by the Bureau as the means of fixing the unit of light. In the agreement between the national laboratories of England, France and America, whereby a common international candle is now being maintained by these institutions, the pentane lamp is stated to have an intensity of ten international candles under standard conditions of atmospheric humidity and barometric pressure and the Hefner nine-tenths of an International candle, likewise under certain standard conditions of atmospheric humidity and pressure, which are, however, not quite the same as for the pentane lamp. The intercomparisons which preceded and led up to the formal agreement were made by means of incandescent lamp standards, the performance of which was so admirable that they have really been employed as primary standards, and the flame standards themselves, which logically should play the part of primary standards, to which the electric standards should be secondary, have been relegated to the subordinate position.

The use of carefully seasoned incandescent lamps as photometric standards of precision is, of course, not new. Professor Fleming of London was one of the first to emphasize their value, and to provide lamps that could safely be used in practice. Two past-presidents of this society, Drs. Sharp and Hyde. have contributed not a little to extending their use and their usefulness. At the Bureau of Standards such lamps have been certified for some years, and recently a very careful study has

[1] A paper presented at the Fourth Annual Convention of the Illuminating Engineering Society, October 24 and 25, 1910.

been made of their preparation and performance. It has been shown that by operating them at constant watts, their reliability as standards is greatly improved, and that a group of well selected carbon-filament lamps has a remarkably long useful life as standards when used at 4 watts per candle, and at constant watts. A study is now being made of metal-filament lamps, to see what their possibilities are as standards of whiter color.

Although electric lamps are very satisfactory as secondary standards, and although as empirical primary standards they may serve to maintain the unit of light constant for many years, yet there is the certainty of an appreciable drift sooner or later if there is no photometric standard accurately reproducible from its specifications which is capable of serving as a reliable check upon the electric standards. Another powerful reason for improving flame standards is their extensive use in gas photometry, to which they are better adapted than electric standards if they are sufficiently convenient and reliable. At the suggestion of some representatives of the gas industry, notably Past-President Gartley of this Society, the Bureau of Standards took up the study more than a year ago of some of the more important of flame standards. Of all the photometric standards which have been actually realized, and which are capable of reproduction from their specifications, the amyl acetate lamp, proposed in 1884 by Hefner von Alteneck, and the 10-c-p. pentane lamp, proposed in 1898 by Vernon Harcourt, are the most widely used, and have been the most investigated.

THE HEFNER LAMP.

The Hefner lamp has had a long and honorable career. Although it has some serious defects, notably its small intensity and reddish color, and requires much patience and skill and many observations to obtain accurate results, it nevertheless has some important merits. If it had not, it would not now be contesting for first place among primary flame standards, after the world has had a quarter of a century in which to replace it by a better one.

Its principal merits as a primary standard are its simplicity of construction and operation, ease of manipulation, portability, durability, and when the fuel is right and the lamps are skillfully handled, the excellent agreement of one lamp with another. Its defects are its small intensity, unstable flame, reddish color, and

difficulty of setting the flame at exactly the right height. For either a primary or a secondary standard these, it must be admitted, are serious objections.

The Reichsanstalt certifies Hefner lamps as correct if within two per cent. of their standard. At the Bureau of Standards there are eight Hefner lamps, four made by one company, and four by another, and all fall within this limit. Indeed, the maximum departure of any lamp from the mean of all is scarcely more than one per cent. However, a primary photometric standard is not entirely satisfactory so long as appreciable differences exist among a lot of lamps made to the same specifications. Accidental errors will, of course, occur in the measurements, but of these eight Hefner lamps certain ones are regularly high and others regularly low, showing that the lamps are not as nearly identical in construction as they should be. This result is due to two things. In the first place, the specifications are not precise as they should be, and in the second place there are in some lamps slight departures from the specifications. That the intensity of the flame may always be the same—under the same atmospheric conditions—it is necessary (1) that the fuel be uniform, (2) that the wick tube shall always be of the same material and dimensions, and (3) that the height of flame be constant. In comparing lamps, the same fuel—and the same kind of wick—are used in the different lamps, and comparisons are made with the same apparatus and practically in the same atmosphere, as they are used in succession by the method of substitution. Hence the differences observed are due (1) to differences in flame height or (2) to differences in the effect of the wick tubes on the size or temperature of the flame.

There are two styles of sight used on Hefner lamps. The earlier form has a horizontal plate, 0.2 mm. (7.87 mils) thick, in the center of the sight tube, and the height of the flame is adjusted until sighting along this plate one sees the tip of the flame in the correct position with respect to the plate. In the other form, due to Krüss, the flame is projected by a lens upon a ground-glass screen, and the tip of the flame is made to fall on a line across the center of this screen. This is the more convenient and preferable form. The eye is fatigued by the naked flame viewed through the first form of sight, and the ad-

justment cannot be made as accurately to the plate as to the line on the screen in the second form. A slightly higher average candle-power is obtained for the lamps having the Krüss sight than for those having the Hefner sight. The authors recommend the use of the Krüss sight only, and for these three separate reasons: (1) It is less fatiguing to the eye, (2) it permits more consistent settings, (3) it makes possible a higher degree of reproducibility by avoiding whatever difference there may be due to using two forms of sight. The flame gauge is satisfactory, and permits a very close reproducibility in the height of the wick tube with respect to the sight. When it is remembered that 1 mm. (39.37 mils) change in flame height represents two per cent. change in flame intensity, and hence the allowable error is only a few tenths of a millimeter in the position of the nearly non-luminous tip of the flame, it is seen that this adjustment is one which requires great care and experience, and an optical device for a sight that is accurately reproducible. Unfortunately, this setting at best is not wholly free from personal equation.

The wick tube affects the flame in several ways. The bore should be 8 millimeters exactly, and this determines to some extent the size of the flame. This dimension is very accurately met in all the lamps. The thickness of the tube is specified to be from 0.14 to 0.17 mm. The wick tube conducts heat down to the liquid amyl acetate which saturates the wick, the top of which is from 1 to 3 mm. below the top of the tube. The thicker the tube the more readily is the heat conducted, and the more readily is the amyl acetate evaporated. Hence, with the thicker tube the top of the wick must be higher in the tube to keep the flame height constant. Also, the thicker-walled tube cools the flame more, and therefore reduces its candle-power more. Hence, the wick tube should be very accurately specified to insure reproducibility. A departure of one or two-hundredths of a millimeter from the mean in the thickness of the wall of the wick tube seems negligible, but its effect is not negligible. To insure strict reproducibility, the weight of the tube should be specified in addition to its bore and its length; the composition of the German silver, of which the tube is made, ought also to be specified, to insure uniform results.

The authors are still engaged in their studies of the effects of slight variations in the dimensions of the Hefner lamp, and have reason to believe that if the specifications are drawn closer and the construction is as exact as it may be, a considerable improvement in the reproducibility will result. However, the lamp alone is not a standard. The photometric standard is realized only when a certain specified fuel is burned in the lamp in a certain specified atmosphere in a certain specified way. The fuel, amyl acetate ($C_7H_{14}O_2$) is readily obtained pure enough to satisfy the specifications. The authors have used amyl acetate bought from a reputable chemical firm which was guaranteed by them to be pure, which did not conform to the specifications, and which gave a flame of different intensity from amyl acetate fulfilling the specifications. Hence, the only safe way in precise work is to test the fuel before using it, or purchase only amyl acetate that has been tested with reference to its use in the Hefner lamp.

The atmosphere affects the intensity of the flame very markedly. Oxygen is supplied by the atmospheric air drawn into the flame. With the oxygen go nitrogen, carbon dioxide and water-vapor, which are not needed for combustion, and which cool the flame and reduce its intensity. If the atmospheric air supplied to the flame varies in its composition, the rate of combustion is altered and the cooling effect of the inert gases varies. Hence, it is stipulated that the room in which the lamp is burned must be well ventilated to secure an atmosphere of uniform composition with respect to the proportions of oxygen, nitrogen and carbon dioxide. The water-vapor must be carefully determined, and the barometric pressure recorded and suitable corrections applied. If the ventilation is insufficient there is an excess of carbon dioxide, and a deficiency of oxygen. A deficiency of oxygen requires a larger amount of air to supply the needed oxygen; hence, a deficiency of oxygen is equivalent to an excess of nitrogen, and the flame is very sensitive to slight variations of that kind. Fortunately, the humidity can be very accurately measured, using an Assman ventilated hygrometer; neither a hair hygrometer nor an unventilated wet-and-dry bulb hygrometer is satisfactory. The humidity correction has been carefully determined for the Hefner lamp at the Reichsanstalt,

and also recently at the Bureau of Standards. The author's result, based on many determinations, is in close agreement with that of Liebenthal, who first determined at the Reichsanstalt this important correction. The correction is linear, from the lowest to the highest humidities observed, and is about 0.56 per cent. per liter of water vapor per cubic meter of air. It is therefore a very important correction, and may amount to from —3 per cent. in dry weather to +10 per cent. in warm, damp weather the lamps giving higher candle-power in dry weather. It is practicable to obtain sufficiently good continuous ventilation to make the error due to variation in the oxygen and carbon dioxide content negligible. The authors much prefer continuous ventilation, rather than to depend upon opening the windows occasionally and working between ventilations.

The flame height specified in the Hefner lamp is 40 mm. (1.57 in.), at which height it gives nine-tenths of an International candle. An extended study has been made of the amyl acetate lamps when burning at a flame height of 45 mm., at which height they give one International candle; at least those with Krüss sights give on an average one International candle. Taking the mean of all, the height should be about 45.25 mm. It is believed, however, that when the wick tube is more accurately specified, and the Krüss sights alone are employed, a flame height of 45.0 mm. will give very accurately one International candle. There is no appreciable temperature-light coefficient to the Hefner lamp between the limits of temperature that are commonly employed. It is, however, steadier, at from 15° to 20° C. than at higher temperatures. Hence for work of highest precision, a comparatively narrow range of temperature might well be specified.

As a standard for comparison the authors use a carbon-filament lamp operated at about 9 watts per candle, which gives a color match with the Hefner. In passing from this color to that of some other standard, there is, of course, the uncertainty due to the color difference, over and above the errors due to the comparisons of lamps of different intensities. That is, however, a question which need not be entered upon here.

In Table 1 is given a summary of results obtained on eight Hefner lamps, two of which, however, are new lamps and have

TABLE I.—SUMMARY OF MEASUREMENTS ON EIGHT HEFNER LAMPS.

Lamp	Weight of wick tube in grams	Flame 40 mm. high — All measurements — No. of meas.	Mean c p. int. candles	Flame 40 mm. high — E. C. C. & A. H. T. — No. of meas.	Mean c-p. int. candles	Flame of 45 mm. high — All measurements — No. of meas.	Mean c-p. int. candles	Flame of 45 mm. high — E. C. C. & A. H. T. — No. of meas.	Mean c-p. int. candles	Percentage of mean deviation from mean c-p. 40 mm.	45 mm.
Hefner sights											
804 K.........	1.246	21	0.889_7	15	0.890_7	17	0.990_7	11	0.992_5	0.74	0.66
879 S-H.......	1.145	19	0.897_3	13	0.898_5	17	0.991_0	11	0.993_7	0.50	0.65
1342 S-H......	1.144	19	0.896_1	13	0.897_3	17	0.991_2	11	0.988_7	0.67	0.92
Mean.......			0.894_4		0.895_5		0.991_0		0.991_6	0.64	0.74
Krüss sights											
786 K.........	1.311	26	0.901_1	19	0.901_1	23	0.997_5	17	0.998_4	0.50	0.65
887 S-H.......	1.153	32	0.907_5	20	0.906_8	25	1.001_9	18	1.001_3	0.44	0.47
1343 S-H......	1.121	33	0.903_2	21	0.901_8	24	1.000_1	17	0.999_7	0.54	0.70
Mean.......			0.903_9		0.903_2		0.999_8		0.999_8	0.49	0.61
Mean of all..			0.899_2		0.899_4		0.995_4		0.995_7	0.56	0.68
New lamps											
1714 K........	1.177	5	0.890_8	4	0.887_1	..	..	..	..	..	..
1715 K........	1.184	5	0.896_8	4	0.895_1	..	..	..	..	..	..

The numbers given above for the several lamps are the numbers placed upon them at the Physikalisch-Technische Reichsanstalt, where all were tested and certified. The letters following the numbers indicate the design.

been compared only a few times. Of the remaining six, three have the Hefner sights and three the Krüss sights. In the first part of the table the results are given for a flame height of 40 mm., and in the second for 45 mm. In the second column is given the number of measurements made on each lamp, a "measurement" being the value found on a given occasion as the mean of 20 or more separate settings on the photometer, and two to five new adjustments of the flame. More than half of the measurements were made by Mr. Crittenden and Mr. Taylor, while the others were made by various persons of less experience with flame standards. For comparison, the results obtained by the more experienced observers are given separately.

The mean value of the first three lamps at 40 mm. flame height (to three decimal places) is 0.896, and of the second three 0.903; the mean of the six being 0.8995 International candles. This is very near, indeed, to the value 0.900 International candles, assigned to the Hefner lamp in the international agreement of 1909.

The mean value of the first three lamps at 45 mm. flame height is 0.992, and of the second group of three is 1.000, the mean of all being 0.996 International candles. This is very near, indeed, to one International candle. As the different lamps vary in candle-power on account of slight differences in their dimensions, the agreement between lamps can be improved, and when the closer specifications are drawn they should be so fixed as to make the candle-power at 45 mm. as near as possible to one International candle.

The average difference of the separate measurements from the mean of all, for each lamp, is given in the last columns of the table, for the measurements of the more experienced observers only. They average 0.64 and 0.49 per cent., respectively, for the two groups of lamps at 40 mm., or 0.56 per cent. for all. At 45 mm. the average is 0.74 and 0.61 per cent., respectively. That is to say, a single "measurement" is in error on the average a little more than one-half per cent. In the case of lamp No. 1,343 at 40 mm., the 21 measurements were divided into three groups of seven each. Calling the mean of each group of seven measurements a determination, we find

	Int. candles		Difference from mean
First determination	0.8997		0.0021
Second determination	0.9017		0.0001
Third determination	0.9049		0.0031
Mean	0.9018	Average	0.0018

Thus, each determination differs from the mean of the three by two parts in a thousand. If the lamp should continue to do as well, and other lamps could be made to agree with it accurately, this would be a very good performance for a primary standard. No reason is known why the lamp should not continue to do as well, nor why different lamps may not be made to agree much better than heretofore. Since the chief differences in the lamps are believed to be due to the wick tubes, it is mainly a matter of careful construction and painstaking inspection, wherein all tubes not conforming to strict specifications, are rejected. Then, if each lamp has three or more tubes, all of which are used in succession, and the mean of the results taken, the accidental unavoidable errors in the tubes will be largely eliminated. If the Hefner lamp were to be adopted as a primary photometric standard, it would be advisable to specify further that the mean value of at least three lamps, each supplied with three tubes (at least 10 determinations being made with each tube), be taken as the value of the unit.

In the above table, the lamp in each group that has the lowest candle-power has the thickest (and heaviest) wick tube. Both are from the same maker. Of the remaining lamps, there are two in which the differences in candle-power are not explained by the differences in the thickness of the tube. Possibly there is a slight difference in the optical sights. This remains to be investigated.

The results shown above are much better than have been obtained heretofore at the Bureau, and illustrate what can be done by experienced observers working under the most favorable conditions. As a working standard under ordinary conditions, much greater errors would, of course, be found.

The authors will continue the studies of the amyl acetate lamp, and report the results in full detail at a later time.

THE PENTANE LAMP.

The Harcourt pentane lamp presents a striking contrast to the Hefner. It is bulky, relatively complicated in construction, less portable, and less convenient in manipulation, more expensive in first cost and in fuel, and requires much better ventilation and a larger photometer room. On the other hand, its higher candle-power, steadier flame and better color are very great advantages. As to reproducibility, a given pentane lamp is more accurately reproducible than a Hefner lamp, when both are operated under correct conditions, but there is a greater difference among different pentane lamps than among different Hefners.

No wick is used in the pentane lamp. The fuel (pentane, C_5H_{12}) is contained in an elevated reservoir or saturator. Air enters the inlet and mixes with the vapor of pentane as it passes over the liquid pentane through the maze into which the saturator is divided by vertical vanes, and this mixture flows down the supply pipe to the burner. In hot weather the pentane may evaporate so rapidly as to flow out through the inlet, and thus prevent the air from entering. In this case, only pentane vapor is fed to the flame. Air, heated by passing through the annular space between the inner and outer chimney, flows down through the hollow standard, and into the central chamber below the burner. Thus the flame resulting from the combustion of the vapor of pentane as it issues from the ring of 30 holes in the steatite burner is fed with preheated air within the flame, while it takes atmospheric air directly through its outer surface. The height of flame is determined by the distance between the burner and the chimney, which is adjusted to be 47 mm., and by the rate of supply of the fuel. The latter is regulated by a stop-cock. The tip of the flame is viewed through a mica window in the lower end of the inner chimney, and must be watched and frequently regulated in work of the highest precision. When the flame is right, its candle-power is a maximum. As with the Hefner the intensity of the flame depends upon the dimensions of the lamp, the composition of the fuel, the atmosphere in which it is burned, and the manipulation of the lamp, especially as regards regulating the flame height and screening the flame.

The specifications of the standard pentane lamp were carefully drawn, and have been closely followed by the several makers of the lamps, with, however, some variations in the American lamps. But that the specifications are not sufficiently exact and complete is shown by the fact that different lamps differ in candle-power appreciably. That is, different pentane lamps burning the same fuel, in the same atmosphere and operated by the same people, differ by as much as two or three per cent., quite independently of the errors of observation. It is not possible, therefore, to take the light of a pentane lamp as 10 International candles under the stated standard conditions. It may in any particular case be only 9.6 or 9.8 candles at standard humidity and barometric pressure, even when the fuel and all external conditions are right.

The total intensity of the light of the flame depends, of course, on its dimensions, and this is affected by the size of the burner. The specifications say that there shall be 30 holes (from 1.25 to 1.5 mm. in diameter) drilled in a circle in the steatite burner, the outside and inside diameter of which are 24 mm. and 14 mm., respectively. But the precise diameter of the ring of holes is not specified, and this is found to vary in different burners. A stricter specification here is desirable.

It is well known that a pentane lamp increases in candle-power for a time after lighting up, and that one should wait from 15 to 30 minutes before taking measurements. The authors know of no careful measurements that have been published to show how or when the light reaches its stationary value. In Fig. 1 are given four curves taken during the heating up period of the lamp, showing that the light increases to a maximum and then decreases to its steady value. This maximum is from 1.5 to 3.0 per cent. above the final value, which is reached in from 15 to 30 minutes. The first two curves are for English lamps, which reach a steady condition in half the time required by the American lamps. The reason for this difference is now being investigated.

The length of the chimney is a very important dimension, and there is little variation among lamps in this particular. The cooling of the flame, due to conduction of heat, varies with the

amount of metal in the lamp and with the details of construction. Possibly the lower candle-power of the American-made lamps is due in part to their more massive construction. This is a point in which the specifications might be more explicit. Further experiments on the cause of variations, due to varying details of construction, are in progress at the Bureau, and the

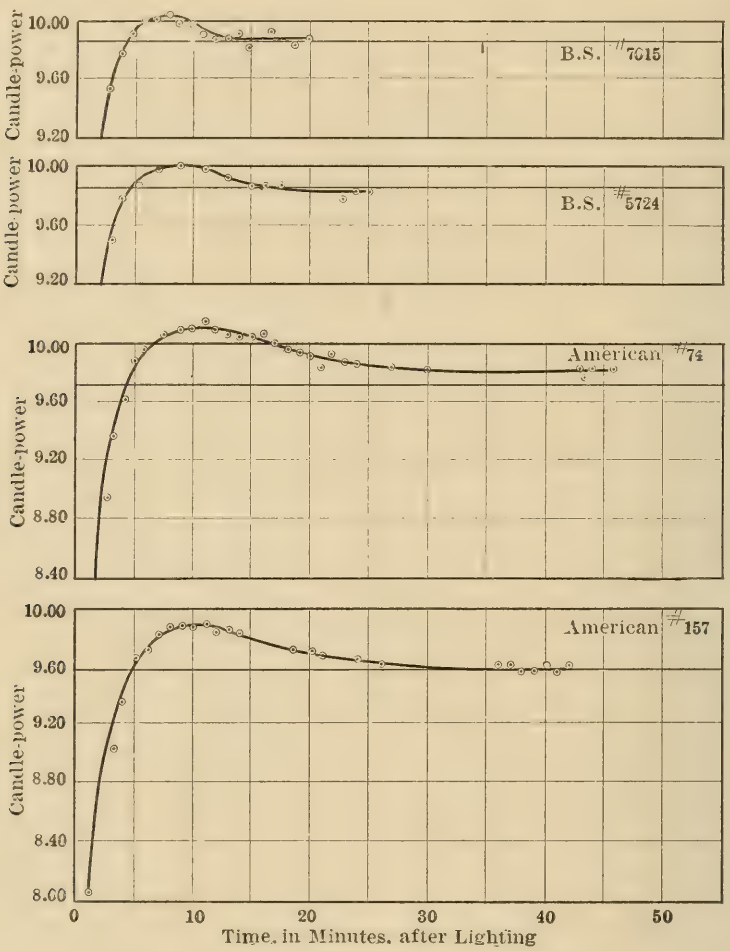


Fig. 1.—Variation of candle-power with time.

hope is to be able to locate the observed differences in different lamps. Although many lamps, both English and American make have been tested, not one has been found that has as high a candle-power as the standard pentane lamp of the National Physical Laboratory, 9.9 candles being the highest value found. Their standard lamp seems to be appreciably above the average, and the English maker of their lamp, from whom the Bureau

purchased two lamps, was unable to duplicate it exactly as to candle-power.

One of the most difficult features of the use of pentane lamps is the fuel. In addition to the inconvenience of pentane being very volatile and explosive, its composition is variable, and as sometimes supplied does not conform to specifications. It is distilled from gasoline, its composition being made nearly uniform by repeated distillation. Besides the great difficulty in separating all the butanes (C_4H_{10}) and all the hexanes (C_6H_{14}), pentane itself (C_5H_{12}) exists in three separate forms, which have different boiling points. Hence, if pentane which complies strictly with the specifications be distilled it may be separated into three portions of appreciably different boiling points. This fractionation goes on in the saturator, and the photogenic value of the pentane changes to an appreciable extent in two or three hours. The official specifications of the London Gas Referees direct that the residual pentane be emptied out of the saturator at least once in each calendar month. For work of the highest precision the authors find that it is desirable to do this every time the lamp is refilled, and that this refilling be done very frequently, not waiting until the pentane is nearly exhausted. Mr. McBride, of the Bureau of Standards, has made a very thorough study of the preparation and testing of pentane, and has analyzed the pentane before it was used by the authors. He has also tested the amyl acetate used.

The humidity correction for the pentane lamp as determined by Mr. C. C. Paterson[1] of the National Physical Laboratory is larger than that found by Liebenthal, and by the authors, for the Hefner lamp, being 0.66 per cent. per liter of water vapor per cubic meter of air. This determination was published in 1904, and it has been adopted generally as the proper correction coefficient to be used with the pentane lamp. In 1906 Dow[2] derived 0.71 per cent., but being obtained from a smaller number of measurements it has been regarded only as a confirmation of Paterson's value. In the earlier works at the Bureau of Standards use was made of Paterson's coefficient in correcting for atmospheric humidity, but it was noticed that the corrected results so

[1] *Electrician* (London), vol. 53. p. 751. 1904.

[2] *Electrical Review* (London), vol. 59. p. 496, 1906.

obtained gave the lamps a higher value when the humidity was high and a lower value when the humidity was low; that is, the correction for humidity was too great. At first this result was attributed to errors of observation and lack of reproducibility of the pentane lamps, but as the work progressed and better results were obtained it became evident that this explanation would not hold. The calculated humidity coefficient from a large number of measurements by the method of least squares gave about 0.57 per cent. instead of 0.66 per cent. Using this lower coefficient excellent agreement has been obtained in the results in winter and summer, and in damp weather and dry. This coefficient has been separately computed for different lamps, both of English and American make, and all give the same value. Moreover, the same coefficient is obtained using only the low range of humidities (4 to 14 liters per cubic meter), or using only the high range (14 to 27 liters per cubic meter) as when the total range is used. In other words, the humidity coefficient is linear from the *lowest to the highest humidities encountered, and is practically the same for pentane and for the amyl acetate lamp.* This is a very gratifying result, and puts the pentane and Hefner lamps in a more favorable position as flame standards.

Having become convinced that the smaller humidity coefficient was correct, at least for the conditions encountered by the anthors, an attempt was made to ascertain why the value found in England was so much higher. Mr. Paterson's work on the pentane lamp is of a high order, and great confidence was placed in the precision of his measurements. It was recalled, however, that formerly atmospheric humidities had been measured at the National Laboratory (as generally in England) by the ordinary wet-and-dry bulb thermometers, without any artificial ventilation, whereas at the Bureau of Standards use had always been made of the more accurate hygrometer of Assmann, ventilated by a rapid current of air, and which therefore gives a greater depression of the wet bulb, particularly at low humidities. The unventilated hygrometer gives fairly correct results if one uses the tables or formula appropriate to that instrument, although it is less reliable owing to the fact that the air in the room is not always equally still. It appears, however, that the formula used

at the National Physical Laboratory was the formula for the ventilated hygrometer, and hence the values of the humidity obtained were too high. The Bureau of Standards some years ago called the attention of the National Physical Laboratory to the fact that, if the standard atmospheric humidity be retained as 10 liters per cubic meter, and the measurements are made by an Assman hygrometer, as the Bureau of Standards was doing and as the International Photometric Commission at Zurich in 1907 had recommended should be done generally, the candle-power of the pentane lamp under standard conditions would be altered, and if its former value were 10 candles it would now be smaller. If, however, it were still declared to be 10 candles, the value of the unit would be altered. The Bureau suggested that the change be made in the number expressing the standard atmospheric humidity, so that the value of the unit and the numerical value of the candle-power might remain unaltered. This suggestion was adopted, and Dr. Glazebrook announced in a paper read before the British Association that the true humidity previously determined as 10 liters by the unventilated instrument was found to be 8, so that the correction formula was

$$\text{Candle-power} = 10 + 0.066\ (8 - e)$$

where e is the number of liters of water vapor in a cubic meter of dry air. The Gas Referees of London, concurring in this proposal, the official value of the pentane lamp has since been expressed by the above equation.

Dr. Glazebrook[1] stated also in this paper that "a complete series of experiments has shown that the constant 0.066 in the formula holds both for the ventilated and unventilated instruments." This means, of course, that the constant is the same when the humidity is computed from observations made on unventilated hygrometers using the formula or tables intended for ventilated hygrometers, the only change in the correction formula being from 10 to 8 in the parenthesis. In other words, the straight line of which the correction formula is the equation has been displaced parallel to itself, its slope remaining unchanged. A little consideration shows that this can only be true under special conditions.

[1] British Association Report, 1908.

An unventilated hygrometer in a dry atmosphere shows a lower depression of the wet bulb than does a ventilated hygrometer, because the air about the wet bulb retains some of the moisture taken up by the evaporation, and thus evaporation is retarded, whereas in the Assmann hygrometer the air moves over the bulb so rapidly that it is always surrounded with air of practically the same humidity as that of the room. Hence, the unventilated instrument will show a lower depression than the other. The difference, which is considerable at low humidities, decreases as the humidity increases and disappears at saturation. That is, the depression of the wet bulb is zero in both instruments in saturated air, and hence they will agree as to its humidity.

Suppose, for example, that a pentane lamp is measured in air that contains 8 liters of water-vapor per cubic meter at 18° C, and again in air containing 20 liters of water-vapor at the same temperature. Suppose its candle-power be found to be 10 International candles in the first case, and 9.32 candles in second. The change of 0.68 candles is due to a change of 12 liters of water-vapor per cubic meter, and since the change in candle-power is simply proportional to the humidity, it is seen that the coefficient is 0.68 divided by 12, or 0.057. If, however, an unventilated hygrometer had been employed and an incorrect formula used, so that the first humidity came out 10 instead of 8, the second humidity would have been correctly shown to be full saturation, which the tables show to be 20 liters per cubic meter at 18° C, then the coefficient found would have been 0.68 divided by 10, or 0.068. This shows that there must be an error in the coefficient found if measurements at different humidities are made at the same temperature. If the higher humidities are at higher temperatures, as they generally are, the error will be less, and it is possible to choose temperatures and humidities so as to get the same error in the water-vapor each time, and thus get a correct humidity coefficient.

In the Weights and Measures Division of the Bureau of Standards, Mr. Pienkowsky has observed readings of an unventilated wet-and-dry bulb hygrometer and an Assmann ventilated hygrometer (both instruments in the same room) for several years past, calculating the humidities from both sets of observa-

tions. The approximate expression for the difference between the pressure f_1 of saturated aqueous vapor at the temperature t_1 of the wet bulb and the actual vapor presssure f in the atmosphere is

$$f_1 - f = AB(t - t_1),$$

where $t - t_1$ is the depression of the temperature of the wet bulb thermometer, B is the barometric pressure and A is a constant depending on the instrument, and on the velocity of motion of the air over the wet bulb.

In Jelinek's tables for a mean barometric pressure of 755 mm, the value of the product of AB is taken as follows:

1. For still air 0.906
2. For slightly moving air 0.604
3. For rapidly moving air 0.495

The coefficient given for the Assmann hygrometer is 0.500. Mr. Pienkowsky has computed the humidity from the unventilated instrument, using the constant 0.906, and from the Assmann, using 0.495, and the results have agreed as nearly as could be expected. When, however, the same formula is used for both instruments, the unventilated instrument, which gives lower depressions of the wet bulb by from 0.5° to 3.0° in actual practice, gives humidity values which are too high by from 1.0 to 4.0 liters of water-vapor per cubic meter of air, the difference depending both on the absolute humidity and the temperature, being less as the humidity is greater, and less as the temperature is lower. It is, however, not the same at the same relative humidity, when both temperature and humidity vary. In order to ascertain what the average difference is between the two methods of obtaining humidity, some of Mr. Pienkowsky's observations have been used to compute the unventilated hygrometer readings by the formula for the other instrument, the differences being plotted against the actual humidities. The mean result is that 10 liters of water vapor per cubic meter of dry air by the unventilated instrument corresponds to 6.0 liters by the Assmann, under the conditions of temperature under which the observations were taken, namely, a temperature of about 20° C. If the laboratory temperature had been 15° C, the difference would have been about two liters. This conclusion has been checked by theoretical

calculations from the formula, using the coefficient 0.906 for the unventilated instrument, and 0.495 for the Assmann. The authors hope to obtain from Mr. Paterson the formula employed by him in determining his humidity coefficient, and also to learn the method by which they obtained the difference of two liters in the standard humidity.

In Table II are given the results of candle-power measure-

TABLE II.—MEASUREMENTS OF PENTANE LAMPS, APR. 8 TO SEPT. 9, 1910.

Lamp	Number of measurements	Mean c-p. int. candles	Mean deviation from mean c-p.
Chance, No. 116	220	9.875	0.03_9
Chance, No. 118	81	9.89	0.02_8
Sugg, No. 171	165	9 62	0.03_8
American, No. 25	42	9.61	0.04_5
American, No. 74	43	9.73	0.03_8
American, No. 157	46	9.58	0.04_1
American, No. 162	31	9.80	0.02_6

ments made upon three English and four American pentane lamps. In the second column is given the number of measurements made on each lamp from which the mean value has been computed. As with the Hefner lamp previously discussed, a "measurement" is the mean of a large number (30 or more) of individual settings on the photometer, the flame being inspected (and adjusted, if necessary) several times during the set. A group of 30 settings (constituting one measurement) on the pentane lamp is made in about 5 minutes, whereas a group of 20 settings on a Hefner lamp requires on an average about 15 minutes. The difference is due to the much greater unsteadiness of the Hefner flame, which often requires waiting for the flame to be steady and at the right height; whereas, with the pentane, settings are made in rapid succession. The method employed of automatically recording the photometer settings makes rapid settings practicable in the most precise work. The average deviation of a single instrument from the mean of all is given for each lamp in the fourth column, and amounts to a little less than 0.4 per cent. on the average. It is less in the late work, probably averaging not more than 0.3 per cent.

In Table III are given the separate measurements in sets of 10, each group constituting a "determination" of candle-power, for four pentane lamps. This is to show the order of magnitude

of the deviations of each measurement from the mean of a group. These variations are due to a considerable number of

TABLE III—SEPARATE MEASUREMENTS OF CANDLE-POWER FOR TWO PENTANE LAMPS.

American Lamp, No. 25.

9.64	9.67	9.61	9.56
9.59	9.67	9.61	9.62
9.63	9.75	9.62	9.58
9.65	9.70	9.64	9.64
9.53	9.65	9.63	9.64
9.53	9.64	9.56	9.62
9.53	9.63	9.57	9.64
9.46	9.62	9.60	9.56
9.46	9.60	9.65	9.60
9.50	9.57	9.59	9.64
9.552	9.650	9 608	9.610

Mean of all = 9.605.

American Lamp, No. 162.

9.75	9.76	9.87
9.79	9.79	9.87
9.80	9.82	9.78
9.81	9.81	9.75
9.83	9.85	9.73
9 80	9.80	9.77
9.80	9.79	9.79
9.78	9.77	9.80
9.79	9.79	9.83
9.81	9.89	9.78
9.796	9.807	9.797

Mean of all = 9.800.

factors, such as variation in the atmosphere, in the fuel, in the effects of drafts and of flame adjustment, as well as errors of the photometric measurements.

In Table IV the results are given of different determination on four American pentane lamps. In the columns headed Δ are the differences from the mean, which average 2.2 parts in 1,000 for all the determinations of candle-power on the four lamps. The error in the mean would, of course, be less than this if the lamps are as consistent with themselves as they appear to be.

In Table V are given similarly results of a larger number of determinations on three English pentane lamps. The 22 de-

TABLE IV.—DETERMINATION OF CANDLE-POWER FOR FOUR AMERICAN PENTANE LAMPS.

Lamp No.	25		74		157		162	
Determination	Int. candles	Δ	Int. candles	Δ	Int. candles	Δ	Int. candles	Δ
1	9.552	—0.053	9.675	—0.052	9.608	+0.032	9.796	—0.004
2	9.650	+0.045	9.754	+0.027	9.591	+0.015	9.807	+0.007
3	9.608	+0.003	9.734	+0.007	9.530	—0.046	9.797	—0.003
4	9.610	+0.005	9.744	+0.017	..	..	..	..
Mean	9.605	0.026	9.727	0.026	9.576	0.031	9.800	0.005

In the above table Δ is the difference between a single determination and the mean of the several determinations given in the table. A "determination" is the mean of ten "measurements."

TABLE V.—DETERMINATION OF CANDLE-POWER FOR THREE ENGLISH PENTANE LAMPS.

Type and numbers	Chance, No. 116		Chance, No. 118		Sugg, No. 171	
Determination	Int. candles	Δ	Int. candles	Δ	Int. candles	Δ
1	9.821	—0.054	9.880	—0.011	9.585	—0.031
2	9.827	—0.048	9.876	—0.015	9.587	—0.029
3	9.846	—0.029	9.933	+0.042	9.612	—0.004
4	9.875	0.0	9.889	—0.002	9.579	—0.037
5	9.910	+0.035	9.884	—0.007	9.590	—0.026
6	9.894	+0.019	9.882	—0.009	9.599	—0.017
7	9.880	+0.005	9.902	+0.011	9.644	+0.028
8	9.911	+0.036	9.884	—0.007	9.616	0.0
9	9.870	—0.005	..	..	9.620	+0.004
10	9.903	+0.028	..	..	9.646	+0.030
11	9.895	+0.020	..	..	9.614	—0.002
12	9.907	+0.032	..	..	9.668	+0.052
13	9.872	—0.003	..	..	9.618	+0.002
14	9.883	+0.008	..	..	9.630	+0.014
15	9.847	—0.028	..	..	9.610	—0.006
16	9.854	—0.021	..	..	9.633	+0.017
17	9.871	—0.004	..	..	..	..
18	9 898	+0.023	..	..	..	..
19	9.858	—0.017	..	..	..	..
20	9.876	+0.001	..	..	..	..
21	9.867	—0 008	..	..	..	..
22	9.878	+0.003	..	..	..	..
Mean	9.875	0.019	9.891	0.13	9.616	0.019

The determinations of the Chance, No. 116, and of the Sugg lamp recorded above were made between April 8 and September 9, 1910, during which period the amount of water-vapor per cubic meter of dry air varied from 4 liters to 27 liters. The determinations of the Chance, No. 118, were made between July 18 and September 9, the range of water-vapor being approximately from 14 to 27 liters per cubic meter of air.

terminations on the first Chance lamp represent 220 measurements, or probably about 10,000 separate photometric settings. The average value of the deviations of the separate determinations from the mean of all is 2 in 1,000 for two lamps, and 1.4 for the third. If the determinations on each lamp be divided up into groups of four, the *mean of each group differs from the mean of all by only one-tenth of one per cent.* This is a gratifying degree of reproducibility. Of course, such results would be obtained only as the means of a considerable number of measurements, even if the flame standards were ideal in their performance, for the errors of the photometric measurements are considerable. That the errors belonging to the flame standards themselves could be so small when measured in all kinds of weather, with a wide range of humidity and temperature, and considerable range of barometric pressure, with many resettings of the lamps, and over a period of some months, would not have been thought possible a year ago.

But, while the value of a given lamp can be determined with so little uncertainty, the differences between lamps are very considerable. The candle-power of the Sugg lamp is 2.6 per cent. less than that of the Chance lamps, whereas two American lamps are slightly smaller in candle-power than the Sugg lamp. It is recognized in England that different pentane lamps differ in candle-power, so that the standard of the National Physical Laboratory is not that of just *any* pentane lamp, nor *the mean value* of a group of lamps, but a *particular pentane lamp.* It remains to learn how to make different lamps agree as closely as a particular lamp will agree with itself, as was remarked above.

The various values of the humidity coefficient that have been computed from the measurements are shown in Table VI. Four of the lamps have been used through a wide range of humidity; three only in the higher range of humidity. The same coefficient is obtained for low and high humidity, and also the same substantially for all lamps. The mean value, 0.0567 candles, for a change in the water-vapor of one liter per cubic meter, found from 628 measurements on seven different lamps, would seem to be subject to very little uncertainty. The different values obtained in England were discussed above.

TABLE VI.—WATER-VAPOR CORRECTION FACTOR FOR PENTANE LAMPS.

Lamp	Number of measurements	Factor derived	Range of water-vapor (l. per cu. m. of air)
Chance, No. 116	220	0.0569	4.0-27.0
Chance, No. 118	81	0.0572	14.1-26.8
Sugg, No. 171	165	0.0561	4.0-27.0
Mean		0.0567	
American, No. 25	42	0.0577	5.0-14.3
American, No. 74	43	0.0558	5.0-27.0
American, No. 157	46	0.0570	18.2-26.8
American, No. 162	31	0.0562	13.7-26.0
Mean		0.0567	
Mean of all	628	0.0567	

In Fig. 2 are plotted the values of candle-power, corrected for variation in barometric pressure but not for humidity, for

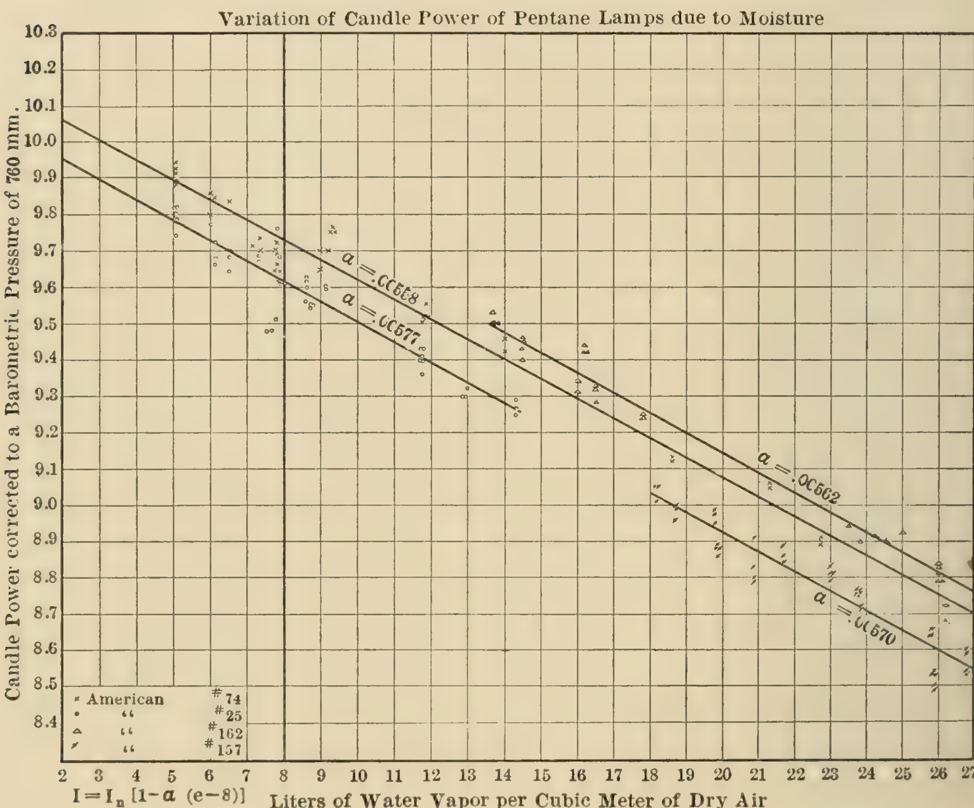


Fig. 2.—Candle-power of four American lamps.

four America lamps while Fig. 3 shows the results for a Sugg and a Chance lamp.

The method of determining the humidity is to ascertain by

means of the Assmann ventilated hygrometer, the vapor pressure in millimeters of water vapor in the atmosphere at the time of the measurements. This divided by the barometric pressure minus the vapor pressure gives the ratio of the water vapor to the dry air with which it is mixed; this ratio multiplied by 1,000 gives the number of liters of water vapor in 1,000 of dry air, that is, in a cubic meter of dry air. This is in accord with English and German practice, and is not quite the same as the

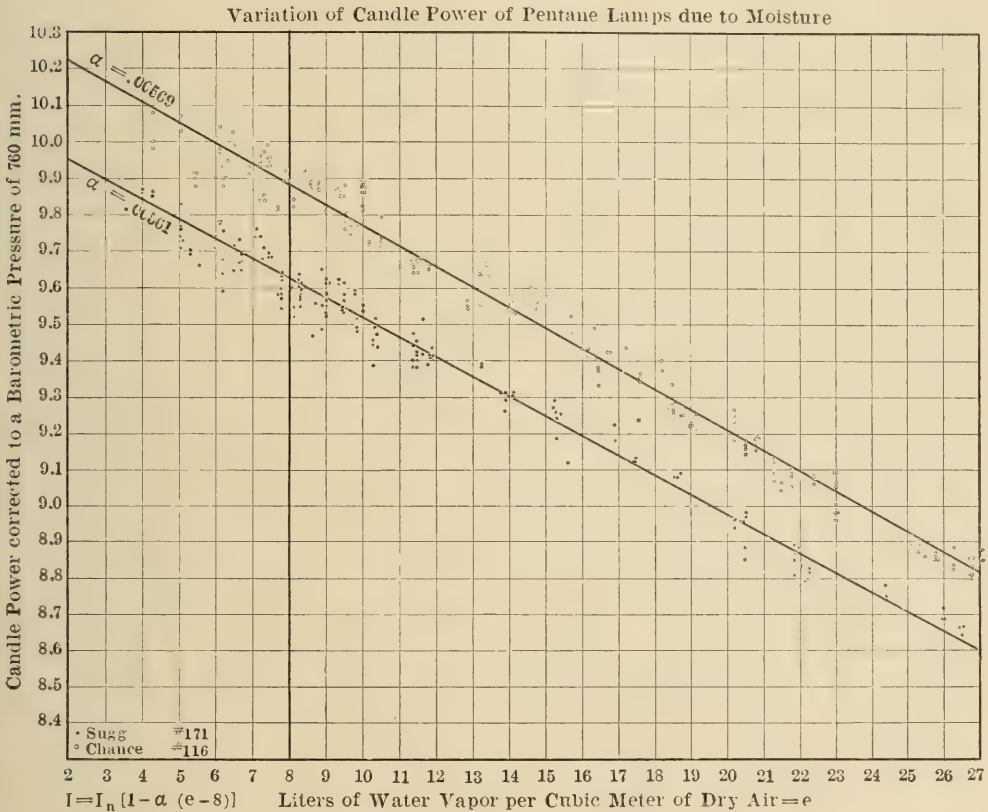


Fig. 3.—Candle-power of a Sugg lamp and a Chance lamp.

number of liters of water vapor (at atmospheric pressure) in a cubic meter of the damp atmosphere.

The author's value for the variation of candle-power with barometric pressure is about 0.6 per cent. for a change of 1 cm. in the pressure. This is not as accurately determined as is the humidity coefficient, because the range of barometric pressures during the period of the measurements has not been very large. The particulars of this determination will be given in a later publication.

Paterson and Liebenthal have made some experiments on the effect on the candle-power of adding small quantities of CO_2 to the atmosphere. The authors made no measurements on this subject for the reason that the carbon dioxide content of pure atmospheric air is very constant, and if, owing to imperfect ventilation, it has increased enough to affect the candle-power, the oxygen will have decreased sensibly, and this will have affected the candle-power more than the presence of the excess of CO_2. That is, the candle-power will be affected very differently according to whether one liter per cubic meter of CO_2 has been added, or so much CO_2 has been produced in the air by combustion. It is considered far easier to insure good ventilation and thereby render correction unnecessary, rather than to try to correct for an excess of CO_2 and a deficiency of oxygen.

The formula for the candle-power of a pentane lamp, used at present by the authors is as follows:

$I = I_n \{ 1 - 0.00567(e - 8) + 0.0006(p - 760) \}$ where I is the measured candle-power, in International candles, of the pentane lamp under the given atmospheric conditions; I_n is the normal value of the lamp, that is, its candle-power at an atmospheric humidity of 8 liters of water vapor per cubic meter and a barometric pressure of 760 mm. of mercury; e is the number of liters of water-vapor per cubic meter, as described above, found by the Assmann hygrometer; and p is the reading of the barometer in millimeters. Putting a and b for the two correction terms,

$$I = I_n(1 - a + b)$$

$$\text{or} \quad I_n = \frac{I}{1 - a + b}.$$

In this paper very few particulars have been given as to the handling of the Hefner and pentane lamps, or the details of the photometric work. The paper is regarded as a preliminary report; in the near future there will be published in fuller detail an account of the work in the *Bulletin* of the Bureau of Standards, in which the authors hope to be able to report further

than they can do now as to the reasons for the differences between different Hefner and pentane lamps.

While much remains to be done on the pentane lamp to make it a thoroughly satisfactory flame standard, the authors feel very much encouraged with the progress thus far, and believe that a much closer agreement between different lamps, and a little higher degree of reproducibility in the same lamp, is possible. For use *as a practical flame standard* in photometric measurements, and for use as a *primary standard* for fixing the unit of light, the same lamp should not be employed, and the specifications should be appreciably different. One would not think of employing an ordinary precision meter bar for a primary standard of length, or of using an ordinary precision resistance box for the reference standards of a national standardizing institution. No more should one think of using a pentane lamp that is not too good for a gas works or for ordinary photometric practice as a primary standard for fixing and maintaining the unit of light. There should be as much difference here as in other physical standards. Mr. Vernon Harcourt has rendered a great service to photometry and to the industries in developing his various pentane lamps, and the authors cannot refrain from expressing their admiration for the thoroughness with which he worked in the pioneer days of precision photometry. But with the increased demand for accuracy of measurement, further improvement is necessary, not only in the construction of the lamp but in its use as well. Instead of using the usual style of lamp, at any temperature and any humidity, with the pentane that satisfies ordinary requirements, there should be a lamp (or several lamps) built as precision instruments to very exact specifications, operated within very narrow limits of temperature and humidity, with pentane satisfying much more rigorous requirements as to density and boiling point, and an atmosphere maintained constant as to oxygen content with great care. With such painstaking procedure the unit of light can be fixed with either the Hefner or the pentane lamp with very considerable precision, sufficient to serve as a valuable check on the admirable electric standards now in use. It is with a view of contributing something to the working out of such precise specifications that

the work of investigation at the Bureau of Standards will be continued during the coming year.

The authors are under great obligations to Mr. R. S. McBride, for his assistance in the chemical examination of the fuels employed in the lamps, and to Mr. A. H. Taylor for assistance in all the photometric work and computations.

DISCUSSION.

Dr. E. B. Rosa:—I should like to say just a word in addition on a point that has not been mentioned in the paper, and that is the sensitiveness of the pentane lamp to drafts in a room. We find that, even when the flame is very carefully screened, drafts may produce changes in the candle-power. The change is due to the fact that the air circulation depends upon the difference in the temperature between the tubes, and a slight draft or a little higher velocity of the air around the lamp will cool the tubes by a different amount, and therefore change the circulation of the air and change the candle-power accordingly. It is necessary, therefore, that there should be a standard method of ventilating the lamp; in other words, it should be contained in an enclosure which should be standard, which should be indicated in the specifications, and the method of observing the humidity and of controlling the lamp should be standardized as carefully as is the lamp construction itself.

Mr. W. H. Gartley:—The electric people are interested in a uniform, fixed, standard, from quite a different point of view than are the gas people. The candle-power of gas has been made a criterion of its quality; many acts and statutes of the States and enactments in the municipalities and regulations laid down by public service boards and so on, require that the candle-power shall be the gauge of the quality of the gas. It would be a matter of great concern to the gas companies if there should be any shifting in that value. Probably 75 per cent. of all the gas that is made in the country to-day is tested according to the candle-power value. Now if a primary standard can be so arranged as to exclude every possible source of variation, as the authors have suggested, and lamps can be sent to the Bureau for standardization, an ultimate desideratum will have been reached, but it is manifest that the lamp that is used by

the gas company will be used with some degree of elasticity. A primary standard could not be handled with the care required nor could it be employed by a gas company without very large expense, expense involving a special building perhaps, electric apparatus and paraphernalia, that would take too long to get together and to be difficult to make the test rapidly, as is required in some cases. A secondary standard or the standard used by the gas company must have some latitude as to the atmospheric condition under which it is used. It must be remembered that, different from electricity, a large portion of the gas that is being used to-day was probably made before six o'clock this morning. Now if atmospheric conditions are going to affect, as they are known to do, the candle-power emitted by the gas, it would be impossible to forecast what the conditions would be from 12 to 16 hours before the time of actual burning. Consequently the gas must be tested with a satisfactory standard that would exactly change in value with the gas flame under these varying conditions. The pentane lamp, as tests which have been made show, does vary with the change of atmospheric conditions, probably more than does any other standards, and particularly the Hefner, for the reason that flames of about the same candle-power are affected in a general way to the same extent; consequently, a 10-c-p. pentane lamp would be affected more than the Hefner lamp; it would be affected more nearly like the 20-c-p. gas. However, another condition of affairs is arising. The calorific value is being considered more and more, and there have been legal enactments throughout the country by which the calorific value is made the standard by which the quality of the gas it to be measured. Of course, this fact does not lessen the necessity of having the good primary standard of the pentane lamp. As the calorific value becomes used the mantle, the reflectors, and all the paraphernalia of the lamp will influence the candle-power, and the light from such a lamp will be influenced less by atmospheric conditions than the naked flame. Consequently, the use of a secondary standard will be lessened, but the use of a primary standard will be just as much as ever.

Mr. F. N. Morton:—In the statement of the humidity of the air as so many litres of moisture per cubic meter is the result

expressed per cubic meter of dry air or of the air as it exists?

Mr. F. E Cady:—Has any study been made of the effect of barometric pressure and humidity on the flame, when the normal height is 45 millimeters instead of 40 millimeters? In other words, is the flame any more sensitive to changes in barometric pressure and humidity when at a height of 45 millimeters than when at the ordinary flame height? In the case of flame standards which have a cylindrical flame, what is to be taken as the center of radiation in measuring the distance? What is the present attitude of the Bureau of Standards in regard to the Carcel lamp?

Dr. A. H. Elliott:—Have the authors tried any other wick material in the Hefner lamp except the one that was furnished with the lamp? I made some experiments in that direction, and found that a common cotton lamp wick, could be used as a substitute for the Hefner wick without any difference.

I am rather glad that the Hefner unit has come out ahead in this investigation, because if there is anything that has made me angry, it is the pentane lamp. I have had no luck with it or pleasure with it for several years and a great many people seem to think of it as I do.

Mention is made in the paper of the expectation of using some of the metallic-filament incandescent electric lamps as standards for the photometer, because they are whiter than the carbon lamps. I should think that their whiteness would render them objectionable because the ordinary flame standards of gas is yellowish or reddish.

The authors appreciate the difference between a chemical compound and a compound like pentane, which means anything. Anybody who has had any experience with gasoline apparatus and knows what gasoline is, knows what pentane is to a large extent. It is a very poor material, and I am a little surprised that the authors have obtained such good results with the pentane lamp as they have. I have worked very faithfully and patiently with the lamps but my results have not been so good.

The authors corroborate observations I have made that the vapor of the pentane comes out at the top of the lamp, and if one is not careful, it will take fire from the lamp below. I do not think that fact is a recommendation for the lamp. I never

heard of an accident with the Hefner lamp. I find it a splendid standard in spite of the fact that it is very small.

The time of lighting as affecting the candle-power of the pentane lamp is far more serious than a great many people think. I find it is a variable quantity. It may take forty-five minutes before the lamp is steady. The change in the form of the flame is another difficult thing, which probably accounts for the variation in candle-power. Then the air and vapor mixture going into the lamp varies. If the temperature is low and the photometer room has a low temperature, somewhere about 55 or 60, the air mixture will contain more or less air in excess, because the evaporation is not rapid, and that fact will affect the candle-power.

In regard to hygrometers, I may state that I have had to do a lot of work in determining the humidity of the air, and the only thing I can find to agree with the Assman hygrometer is a determination of the humidity in the air by the use of solid glacial phosphoric acid. Chloride of calcium or sulphuric acid determinations of the humidity in the air, by drawing measured quantities of air through apparatus are misleading, especially the chloride of calcium determination. The only apparatus that corresponds in agreement or is at all in harmony with the Assman hygrometer is the swinging bulbs—dry and wet bulb thermometers that swing on a handle, made by the various scientific instrument manufacturers. If the thermometer be put on a handle and swung at a certain speed, the results correspond almost exactly with the Assmann hygrometer; this outfit is less expensive. I have tried both, and it would be immaterial to me which one I used.

Mr. C. O. Bond:—At the time the pentane lamp was developed by Mr. Harcourt, it is unlikely that he made use of so constant a standard as the incandescent electric lamp in determining its average value to a high accuracy as the authors have now so successfully done. Yet the fact is that that particular pentane lamp to which the authors refer as being the standard recognized in England, and kept at the National Physical Laboratory, still exists and is in the same condition probably that it was when the value was assigned to it. I am wondering whether the change that may be made by applying the authors formula of cor-

rections for water vapor, instead of the one Mr. Patterson uses, will bring about with the English people any question as to holding up the new International unit which was practically thought agreed upon. It may be possible that there will be a slight discrepancy between the value given to that English lamp measured under moisture conditions as Patterson states them and as measured under the conditions which the authors now find should be used. It would be a most regrettable thing if the entire subject of the International candle should be opened up again.

Mr. Crittenden:—In regard to the content of water in the air, it is to be noted that the number of litres given in the paper is the number of litres per cubic meter of dry air; and therefore not exactly the same quantity would be used in the chemical determination as is ordinarily given. The statement that the pentane lamp and other lamps of larger candle-power vary more nearly in proportion with the gas flame of twenty candle-power, is not valid, I believe, because the variation is a matter of percentage. It is interesting to note that according to the results reported in the paper, the percentage of variation in the flame standard is practically the same for the Hefner as for the pentane standard; in fact, the constants have come out to be 0.56 per cent. for the Hefner, and 0.567 per cent. or 0.567 per cent. in round numbers, for the pentane. In other words, the two standards, according to our work, have operated the same way, which incidentally renders reasonable the assumption ordinarily made that the gas flame varies in proportion with the standard itself, and in that way strengthens the use of this standard for the testing of gas. I will mention that in some work on other flame standards of various kinds, we found a similar variation, a factor of 0.55 per cent., or practically the same value. In other words, the assumption ordinarily made, that all flames vary in practically the same way, seems to be borne out by these constants as they have been found to do.

With regard to the effect of atmospheric and barometric changes on the Hefner as operated at 45 millimeters instead of 40 millimeters, we have made some determinations, although our measurements have been more limited in number, and the coefficients found are practically equal. The number of observations has

been relatively small, but the variation factor there has been 0.53 per cent. as compared to 0.56 per cent. at 40 millimeters. In other words there in only a variation which might well be due to experimental error. For barometric variations, we really have made no determinations on the 45-millimeter height. When it is realized that the variation for one millimeter on the barometer is only 0.01 per cent. it will be appreciated that quite a number of observations will be required to get reliable values for the constant. It happens that Liebenthal's value for the barometric correction factor for the Hefner lamp is given as 0.00011. The mean of our values on the six lamps has come out 0.00014, which we consider as a very close agreement. This value was for the 40-millimeter height instead of the 45. There seems to be no reason for believing, however, that the variation should be greatly different in the case of the 45-millimeter height.

As to the question of the center of radiation, we have in each case followed the practice which we believe well established in the laboratories in which the lamp is used; that is, we have used the center of the flame—the geometric center—as the center of radiation. That location may not be exactly accurate for the pentane lamp, but it is the practice I believe in the National Physical laboratory, and if it is universally followed, it does not matter what is taken for the center, so long as all agree.

We have had little experience with the Carcel lamp, and we agree with most who have tried to use it that it is unsatisfactory The variations from the mean were probably 2.0 per cent. on the average compared to less than 0.5 per cent. in the case of the pentane lamp. Therefore, we have not considered the Carcel lamp seriously at all.

It has been well established that the nature of the wick material in the Hefner lamp is unessential; that is, it may be a loose string or it may be a woven wick, or anything else that draws the fuel up to the top of the tube, where it will be evaporated. As the wick is not burned at all, it serves merely as a conductor to bring the fuel up to the hot part of the tube. In operation the wick is from one to three millimeters below the top of the tube where it serves as a capillary conductor and not as a burning material at all.

On starting we were quite discouraged with the pentane lamp and quite ready at times to throw it in the junk heap, but we have rather reversed our opinion. We are now glad to work with the pentane and get away from the Hefner, so that our statement was not meant to imply that the Hefner is preferable to the pentane. As to the standards used in measuring the lamps, the metallic filament standards mentioned in the paper were not to be used for this purpose but for other work. The color of these flames is much redder than the ordinary 4-watt-per-candle carbon standard, so that for this particular work we have calibrated a set of standards running at low voltage, consuming approximately 9-watts per candle, for use with the Hefner lamp, and about 7.5 watts per candle for the pentane lamp.

As to the fuel and the danger in using it, it is true that the evaporation of pentane with its escape into the air, through the air inlet, has an element of danger. In one instance at least, operating in hot weather, the pentane caught fire at the top of the lamp, but it was checked by simply turning off the stop-cock, and no explosion resulted. In fact we have grown rather careless in handling the lamp because we have used it under all sorts of conditions without accident. Still there is the possibility of an explosion which is not present in the case of the Hefner lamp.

Concerning the time of lighting, we find ordinarily that with the English lamp fifteen minutes is plenty of time for the candle-power to reach its steady value. In the case of the American lamp, the time required is half an hour, or sometimes slightly over, after which the values are very steady; the difference is probably due to the greater amount of material which has to be heated in the American lamp, and therefore a longer time is required to reach a state of equilibrium.

The Assmann hygrometers have been found to be very reliable. We have used three different instruments, purchased several years apart, and the variation of reading between them is practically negligible. That is, readings on two different instruments will agree usually within 0.1 degree, and seldom differ by more than 0.1 degree.

President Hyde:—Has any evidence whatever been found of a temperature effect due to the room temperature? There are

one or two reasons why that is not inconceivable. In the first place, the flow depends to some extent upon the temperature relations in the lamp itself; and secondly, the composition of the gas in the pentane lamp varies greatly with the temperature. At high temperature pure pentane is obtained through the burner, and at comparatively low temperature a considerable quantity of air is mixed with the pentane, I recall there was some slight evidence,—though our observations did not go far enough when I was working at the Bureau—of a temperature effect. Has any further indication of that effect been found?

Mr. Bond:—Mr. Crittenden brought out the point about there being danger of ignition from pentane vapor backing through the inlet to the saturator box. Perhaps this is a partial reason for the practice followed by Mr. Patterson in standardizing lamps at the National Physical Laboratory. He connects a rubber tube to this inlet, leading it down to a position near the table and lower than the flame, so that any vapor backing through would, by its weight, continue to descend and thus avoid possible ignition at the flame. It is also possible to regulate the air supply by a pinch-cock at the lower end of this tube. I wish to inquire whether the authors have ever used that method and whether they found it made any difference in the value of the lamp as compared with the usual method of regulation.

Dr. Rosa:—As to the question about the humidity in the air, I may say that we should prefer to express the humidity as so many litres per cubic metre of the atmosphere, as is usually done, but in this particular we have followed the practice of Germany and England; that is, we express the number of litres of water vapor per cubic meter of dry air rather than of the atmosphere itself.

As to the question of the center of radiation, in addition to what Mr. Crittenden has said, I would suggest that in a primary standard it would be an advantage if the distance at which the flame is measured be specified. For example, if the centre of the flame is one meter from the photometer screen, and is always measured at one metre, any uncertainty due to slight variation of the center of radiation from the axis, would be eliminated. In other words, in a primary standard, to fix the unit of light all

possible chance of variation ought to be eliminated, and to specify the distance I think would not work any hardship and would ensure that the measurements were made under more nearly uniform conditions.

Dr. Elliott's statement that the pentane is almost anything, should be qualified. Pentane is not quite definite as it ought to be, but it is not so very different from what it ought to be if it is prepared according to closer specifications than is done now. Pentane that passes the specifications is distilled between temperatures of 25 and 40 degrees. That is a pretty wide range; and there are present three forms of pentane. That is to say, C_5H_{12} is a compound in which the carbon may be linked up with hydrogen in three different ways, and thus there are three forms of pentane having the same percentage composition, and the same formula, but not the same structure. Instead of including all three together with some butane below, and some hexane above, the distillation might be made between closer limits to exclude more completely the butane on the one hand and the hexane on the other, and include chiefly the middle one of those three pentanes. If there were specified only one pentane with just a little of either of the other two, instead of allowing three, the results would be very satisfactory, because, as a matter of fact, there is very little difference in the light-giving value of the three pentanes. As to whether this would have any effect upon the value of the International candle, we cannot say. It would be for the National Physical Laboratory to work that out. They have preserved the International candle in terms of electric standards as we have done. They have satisfied themselves that the electric standards agree with the pentanes, but for precise measurement, it is the electric standards that they trust rather than their lamp. They standardize their pentane lamps against the pentane lamp, but the electric standards, with which the principle part of their work is done, are standardized against their electric standards, and I should therefore expect that they would maintain their international unit by means of the electric standard. Just how they will reconcile the fact that different pentane lamps give different values I cannot say. It is evident to us from our work that before the pentane lamp can be considered a satisfactory

primary standard its specifications must be very much improved and made closer, and that will require international action, or at least ought to receive international consideration.

There are at least four different things in which we should confer with other countries. One is in regard to the unit of light. We have what we call, or propose to call, the international unit of light used by three countries. If that unit could be extended to the whole world, very great advantage would result. In order to do so requires international consideration. There is also the question of the specifications of the two flame standards. If they should be changed in this country, the change would perhaps not be accepted abroad. In order that they may be accepted and be general, international consideration must be given to the question of a primary standard; either the pentane or the Hefner, it would seem under better specifications, would be a fairly good primary standard. There are also subject to international considerations the methods of measurement that is, the matter of passing from one color to another in heterochromatic photometry, as well as the nomenclature question. Instead of there being oniy the one question of nomenclature there are four. I should like to suggest that at the proper time there be appointed a special committee by this Society to consider the most feasible way of bringing about international agreement and uniformity on these four questions. Perhaps this is not the proper time to make a motion, but I should like to see the Society take action upon the subject.

THE VALUE OF ILLUMINATING ENGINEERING TO THE COMMERCIAL MAN.[1]

BY WILLIAM J. SERRILL.

The writer has heard the opinion expressed that illuminating engineering is an abstruse technical science, with only an indirect, or remote, bearing on practical questions; and, consequently, that the commercial man of the electrical or gas interests, can derive little of benefit from the study of this science, or from attendance at the meetings of the Illuminating Engineering Society. The object of this paper is to show that the opinion here described is erroneous.

For the present purpose, the subject may be divided into three classes, namely:—First, the design and development of lighting units; secondly, the determination of the light distribution and of other characteristics of the available units; and thirdly, the application of the available units to the spaces to be lighted, as determined by the illumination requirements.

It is evident that the commercial man is dependent upon the illuminating engineer for the design and development of the electric and gas lamps which he has available to offer to the public. The physical and chemical principles underlying both of these forms of illuminants are abstruse, and each has reached its present efficient form through invention and research on the part of scientific men. The commercial man may well say, "It is not necessary for me to master these scientific principles; I accept with thanks and put on the market the latest products of such invention; if I am free to criticise, and to state what my experience as a salesman indicates is required by the public, and if the engineers meet these requirements, I am satisfied."

It may be admitted that the commercial man need not master the principles underlying the design of lighting units, but the statement just put into his mouth shows how essential is a constant co-operation and exchange of opinion between the commercial man, and the laboratory man. The latter is to a large

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extent dependent upon the former for a knowledge of the public taste, and of the extent to which the public purse will be opened to its gratification. In addition, the commercial man will understand the requirements demanded by the various kinds of buildings and of occupations, as affecting such points as the size of the unit, the distribution of light from it, its color, its daylight appearance, etc. The association together of these two classes of men at the sectional and annual meetings of this Society cannot fail to be of benefit to the art of illumination. If on this point, it may seem to the commercial man that he imparts more than he receives, he should realize that it is in a good cause, and will result in the production of more efficient units, better adapted to the requirements of the consuming public.

It is evident that the commercial man, having at his command an assortment of lighting units, must, in his effort to sell them, be possessed with a thorough knowledge of the salient characteristics of each of the units. For this knowledge, he is dependent upon the illuminating engineer. The illuminating engineering laboratory with which the writer is connected, has furnished, or is now engaged in preparing, information regarding the gas lamps that are being sold, as follows:

Light distribution curves of lamps and globes; luminous efficiencies of lamps, globes and mantles; minimum distance from the ceiling it is safe to hang the lamps; safe distance under awnings for outdoor lamps; windproof qualities of outdoor lamps; relative emission of radiant heat from gas and electric lamps; relative intrinsic brilliancy of lamps fitted with assorted glassware; proper heights of lamps of various types, suitable for various purposes; reflective efficiencies at various angles, of various lights with standard wall papers; absorption co-efficients of glassware; ignition devices; color values of the light from various lamps; strength of mantles; adaptability of lamps to various gases and pressures; loss of efficiency, during service, of lamps and mantles; examination of lamp structure and suggestions for remedy of structural defects.

Knowledge of the kind indicated in the above list is essential to the commercial man in his effort to sell, and to meet the competition of other forms of illuminants. Here there is

reached another point which emphasizes the importance of the commercial man attending the meetings of the Illuminating Engineering Society. At the meetings he learns how to interpret and utilize the data furnished by the laboratories. The subjects contained in the above list are of the sort that are considered and discussed at the meetings. Any salesman listening to, and taking part in, the discussions, thereby improves his efficiency by increasing his knowledge of the thing he sells.

Having considered the laboratory end of illuminating engineering, and having shown the value to the commercial man of his participation in the discussion of subjects connected with that branch, it is well now to approach the third division, that of applied illuminating engineering.

In considering this subject, one is met at the outset by the startling fact that the application of lighting units to interiors is, and from the nature of conditions must be, made by the commercial man. In any city, the electric light company and the gas company, through their canvassing departments, handle such work. There is, to be sure, the consulting illuminating engineer, who may plan a fraction of it, but it remains true that the great bulk of lighting installation work is carried on by the gas and electric interests. In the stress of competition, these interests actively canvass, and thus secure the work.

Now canvassing for light is, like other canvassing, essentially commercial work. It is organized and carried on for a direct and immediate commercial purpose, and it must be directed by a commercial head. The atmosphere of a department where canvassing is carried on, should be charged with the commercial spirit. Engineering departments, from the nature of their duties, do not develop among their employees, the selling instinct. The writer does not mean to imply that an engineering education is not helpful to a salesman, or to any one in charge of a selling department. The point he wishes here to make, is that a canvassing department, to be successful, should be organized as such, and should devote its energies exclusively to that purpose.

In canvassing for light, the conditions are such that generally the character of the installation must be determined by the canvasser, during his visit to the consumer's premises, and frequently in the consumer's presence. The stress of competition,

and the sensibilities of the consumer, generally combine to make the element of time an all-important factor. The prospective customer says: "Here is an interior. Can you light it satisfactorily? Can you improve on its present lighting? How much money can we save by installing your system?" In order to secure the work at all, the canvasser must be prepared to give an immediate answer to these questions, and, in so doing, he is determining the character of the installation his company will make, in case it gets the order. In other words, the canvasser is doing the applied illuminating engineering. The fact that the orders so taken may be given to an engineering department to install, and that in this way, the plans of the canvasser may be checked, and corrected if mistaken, is not to the point. Occasionally such a change might be made, but many cases of this kind would seriously affect the business.

Having shown that practical considerations force the application of lighting units to interiors into the hands of the canvasser, it should be unnecessary to furnish an additional argument toward the education of the canvasser in the principles of illumination. Each company must solve for itself the problem of imparting this education; upon its success will depend whether or not the interiors covered by its field of operations, are properly lighted. In the writer's opinion, the Illuminating Engineering Society should become an active factor in the education of the lighting canvasser. Especially should the local sections take an active part. In these, more time should be given to discussions of actual installations. Such installations, illustrated by diagram or photographic slide, when criticised and discussed in public meeting, have a high educational value. Commercial men, members of local sections, should be encouraged to present descriptions of such installations, and of interesting problems that arise in their experience.

The Illuminating Engineering Society has been adversely criticised for devoting its energies too exclusively to the abstract chemical, physical and physiological problems that pertain to the profession. Even if the charge be true, the adverse criticism is not deserved. The profession of Illuminating Engineering is emerging from the state of infancy; it is proper that the scientific principles which underlie the profession should have been mas-

tered, before the more practical phases of the subject come to the fore. The Society is now in position to devote more time to the latter. It has been suggested that the annual sessions should consume four days, two being devoted to the scientific, and two to the practical, branches of the profession. The purely commercial phases of the sale and introduction of lamps should probably not be considered by this Society.

At this point some commercial man arises and protests somewhat as follows: "The practice of illumination is an art, and the main qualification of the person who practices this art is experience combined with common sense. It may be true that the art is based on scientific principles, more or less abstruse, but a knowledge of these principles is not essential, any more than in the art of preparing food, the expert cook must be acquainted with the chemical and physical changes brought about by the application of heat to animal and vegetable tissue. I grant my man must be thoroughly familiar with the lighting units, and the accompanying glassware, and must be able to interpret the light distribution curves and other data furnished by the laboratories, but when it comes to the actual application of the units to the space to be lighted, judgment based on experience, is the only tool he needs. There may be some cases of such complication that he may need the advice of an expert illuminating engineer, but they are few and far between. Practical conditions in most cases prevent an ideal arrangement of the lamps; these practical conditions are so numerous and so compelling as to become the dominant factors, so that the best illumination obtainable is a compromise. Outlets are fixed, and it is expensive or inexpedient to change them; the ceilings are low; columns, showcases, balconies, etc., interfere; these and numerous other practical consideration are such that, in the great majority of cases, the installation made by the consulting illuminating engineer, after calculating the illumination at all parts of the room, will be identical with that made by an experienced man, using nothing but his judgment as a guide."

The above remarks of our commercial friend are interesting, and contain considerable of truth, but there is in them no argument against the proposal to educate the lighting canvasser in the principles that underlie practical illumination. No one can

argue that a knowledge of these principles will detract from this man's efficiency; very few will have the temerity to argue that such a knowledge will not be of positive value to him.

The practice of illumination is indeed an art, but is it not also something more, namely, a profession? Those arts in which the processes are so simple that no knowledge of the underlying principles is needed in order to practice them, are arts pure and simple; in proportion as the processes become complex and involved, and as the problems contain many variable quantities, a knowledge of these principles becomes essential, and the art merges into a profession. Shining shoes and washing clothes are arts in which the processes are simple, requiring on the part of the boot-black and washer-woman no knowledge of the chemical and physical changes involved. Cooking is to a certain extent such an art, but the frequently-urged claim that it is practically a lost art, is due to the fact that most of the cooks are "practical" cooks, and that too little attention is paid to a knowledge of the underlying principles. The more complex the problems involved in illumination, the more numerous the practical obstacles, the more essential becomes a knowledge of, and a constant reference to, the principles which underlie the profession of illuminating engineering.

A word of re-assurance may here be advisable, lest the commercial man be frightened at the vast extent of learning that is expected of him. The TRANSACTIONS of this Society, as one turns them over page by page, present many formidable propositions to any one who is not a trained scientist or an expert mathematician. The commercial man may be comfortable in the thought that these are not for him. The principles he needs are relatively simple, and such as he can easily grasp, if he appreciates their importance, and seriously applies himself to them. He should learn how to determine the amount of illumination from the curve of the lighting unit when the units are spaced at any given distance and height; and how to allow for the effects of reflection from walls and ceiling. He should maintain a drawing board for his own use, and should use it constantly, never guessing at the result when it may be ascertained by proper calculation. Most formulas that he needs in his work are given in table form for his convenience, and

constants are provided for his use; it is not absolutely necessary that he should understand the derivation of the formulas, or the laws on which the constants are based, but the more he understands of them the better. He should practice to think and judge of illumination in definite units,—in foot-candles; and to enable him to do this, he should understand the use of the portable illuminometer, and make constant use of this instrument in reading the actual illumination obtained by the equipments he installs. There is no better way to train the judgment than this constant checking of calculations by results. He should be a constant attendant at the meetings of one of the local sections of this society; even although he may not follow every argument or calculation, he will surely absorb from every discussion some grain of knowledge which will enable him more intelligently to meet the demands of his calling.

The profession of illuminating engineering deals with an important subject, fraught with grave consequences to the future of our race. Conserving the most vital one of those five senses which form the connecting links between the personality of the individual and the physical world, it is destined to exercise an important influence on the progress of civilization. It enlists the services of the physicist, the chemist, the mathematician, the physiologist, the oculist, the manufacturer, the architect, the artist; and in this list the commercial man holds an honorable and commanding position. No one, two, or three, of the types of men here named, can solve the multifarious problems of the profession. It requires the services, and the co-operation of them all. The profession cannot afford to have any one of them hold aloof; and it will prosper in proportion to the degree of co-operation, and of interchange of opinion, that is maintained, and to the extent to which those individuals who compose each group, endeavor to broaden their views by obtaining as great a knowledge as possible of the activities of the other groups. The commercial man cannot afford to remain ignorant of the progress of illuminating engineering. The best basis upon which to build the knowledge and experience of salesmanship in this commodity, is a familiarity with the principles of illuminating engineering.

THE VALUE OF ILLUMINATING ENGINEERING TO THE MANUFACTURER.[1]

BY V. R. LANSINGH.

The different classes of manufacturers who are engaged in supplying things necessary for artificial lighting and who are directly benefited by the subject of illuminating engineering may be roughly classified as follows:

A. The manufacturer of artificial illuminants.

B. The manufacturer of shades and reflectors.

C. The manufacturer of appliances used with artificial lighting.

D. The manufacturer of contributing apparatus; that is to say, apparatus which is necessary finally to produce artificial light.

E. The manufacturer of electricity or gas; for example, the central station or the gas plant. This last class is covered in convention papers by Messrs. Serrill and Gilchrist and consequently will not be considered here.

Taking up the first class; namely, the manufacturer of illuminants, this can be divided into four sections; namely, electric, gas, acetylene, gasoline. In the scope of this paper it will not be necessary to analyze the value of each of these divisions separately, but they can be considered as a whole.

A. BENEFITS TO THE MANUFACTURER OF ILLUMINANTS.

The products put out by the manufacturer will be used more correctly and consequently will give better satisfaction, which will lead to their wider use.

By a knowledge of illuminating engineering, new fields for the manufacturer will be opened up.

A knowledge of illuminating engineering will teach the consumer to choose correctly the character of illuminant desirable for the work in hand which will lead to a wider extension of such illuminant for such work.

Illuminating engineering improves the quality of the manufacturers' product.

[1] A paper presented at the Fourth Annual Convention of the Illuminating Engineering Society, Baltimore, October 24 and 25, 1910.

Illuminating engineering teaches the salesman of the manufacturer to solicit business intelligently, placing him in a decidedly advantageous position over his competitor who has not this knowledge.

It puts the manufacturer employing such methods above his competitors not employing them, making it therefore more easy to sell his goods.

These advantages may well be discussed more in detail. One of the greatest complaints of the manufacturer of illuminants is that the public does not use his product as it is intended to be used and consequently the customer does not get the satisfaction which he was led to expect from the manufacturer's statement. Thus, in the case of the incandescent electric lamp, the customer orders a lamp of 110 volts when perhaps he should have ordered one for a 105-volt circuit. The result is dissatisfaction and results in the loss of future business to the manufacturer supplying the lamps. In the case of the yellow flaming arc lamp, it is sometimes seen in front of a store window where the storekeeper is attempting to show color values. The bad results consequently obtained may lead to the condemnation of the lamp simply because it was used in the wrong place. A notable example of this was the use of the mercury-vapor lamp in its early days in many places where it should not have been employed with the consequent condemnation of the lamp, which greatly retarded its introduction in such places where it was entirely suitable. Similar examples might be cited in other fields, but those given will probably make the point clear.

It is self-evident that a knowledge of illuminating engineering opens up new fields which heretofore were unavailable. For example, in automobile head-lamps the field was almost entirely in the hands of the acetylene industry until by the introduction of illuminating engineering principles (illuminating engineering is here used in its broadest sense) the manufacturer of electric appliances has been able to compete successfully. This condition required a thorough knowledge on the part of the manufacturer, not only of the manufacture of a suitable lamp and the proper length, shape and position of its filament, but also the use of it

in conjunction with the proper reflector with an adjustable method of focusing. Had not all of these combinations been properly employed the field would have been closed to the manufacturer of the incandescent electric lamp. It is exactly along similar lines that the acetylene industry has gained such a hold in automobile lighting as compared with the lighting by means of oil lamp first employed and still employed on many automobiles.

In the industrial field it is found that knowledge of illuminating engineering is of the utmost importance to the manufacturer of electric illuminants, as is evidenced by the fact that one interest has devoted some $50,000 toward making investigation as to the requirements and the method of solving the problem of industrial lighting. Before the manufacturer can hope to invade such fields he must make a thorough study of all the conditions, such as the placing of the units, the size of the lamp, the height above the floor, the color of the light, and many other problems which can only be solved by a thorough study. Examples of the benefits to be derived by the manufacturer in the study of these problems might be multiplied many times, but one other example will suffice. In the field of street lighting the old open direct-current arc lamp giving the maximum candle-power at 45° was almost universally employed in the early days of electric street lighting. A careful study of the problem showed that these lamps were far from being ideal for street lighting, and a thorough study of the problem, which is still being continued, has shown that illuminants of different characteristics are desirable, and there has therefore been introduced for such work the enclosed arc, the magnetite arc, the flaming arc, as well as different forms of incandescent electric illuminants. In the case of gas street lighting, the old open flame burner has been almost entirely superseded by the mantle burner, either singly or in clusters, as for example the high-power high-pressure incandescent gas mantles used for lighting many of the cities of England and the Continent. It was only by a knowledge of the distribution and character of the light that the manufacturer has been able to introduce his product against the competition of the older and more firmly established illuminants.

A knowledge of illuminating engineering improves the quality of the manufacturers' product. The manufacturer who would improve his product calls to his aid many of the different branches of illuminating engineering using this term in its broadest sense. He calls upon the chemist, the physicist, the glass maker, the shop process man, the selling organization for their experience in things desirable, and by means of all of these the product is gradually raised in quality, due to the wider knowledge of illuminating engineering. For example, in this country the quality of the incandescent carbon lamp has gradually been raised so that to-day a lamp of from 2.5 to 3 watts per candle is obtainable, where formerly for the same length of life a consumption of from 3 to 3.5 and even 4 watts per candle was necessary; while in England, where little is as yet known of illuminating engineering and where commercial methods have not the same tendency to advance it as they do here, the lamps reach as high as 8 or even 10 watts per candle resulting most disastrously to the introduction of electric light in competition with gas. Summing up, therefore, it may be safely stated that one of the greatest values of illuminating engineering to the manufacturer is the resultant improvement in the quality of the illuminant he makes.

It teaches the salesman to solicit business intelligently and a salesman equipped with a knowledge of illuminating engineering cannot be placed in the same class as one without this knowledge. This is so well recognized to-day that the trained illuminating engineers who also have selling ability, command the higher salaries and are of far greater value to the manufacturer than those without this knowledge. This condition is so rapidly increasing that with the growing knowledge of illuminating engineering among the buying public, the companies whose salesmen have been best educated in illuminating engineering are those who are making most rapid progress.

In a like manner it puts the manufacturer using illuminating engineering above his competitors who are not employing such methods, for the manufacturer is, after all, nothing but a salesman, and what is true of the salesman is also true of the manufacturer. This is well evidenced by the recent rapid progress

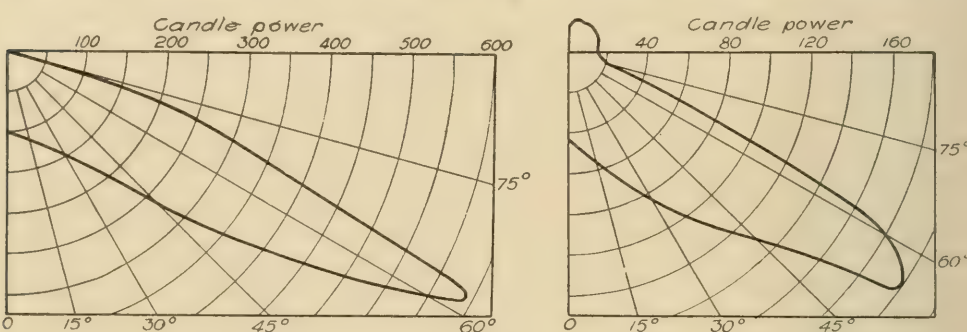
made by the manufacturers of incandescent electric and gas illuminants who have made illuminating engineering departments part of their regular organization.

B. BENEFITS TO THE MANUFACTURER OF SHADES AND REFLECTORS.

To the manufacturer of ordinary glass shades which are designed primarily for decorative or diffusing purposes, a knowledge of illuminating engineering is of value. As an example can be taken the question of the color of illuminants and its relation to the glassware used. Thus if a glass manufacturer wished to obtain a glass for home lighting which would give a warm color to the eye but at the minimum loss by absorption, he would employ a different glass for tungsten lamps from that he would use with carbon, since in the latter case it is not necessary to employ as much color as in the former. Similar examples of the value of illuminating engineering to other branches of ordinary decorative glassware might be easily multiplied, especially in the physiological and psychological effects it is desired to produce.

In discussing however, the subject of reflectors, it is at once evident that a thorough knowledge of illuminating engineering not only in its broadest sense but in its more narrow and usual application, must be employed. Thus, in the case of prismatic reflectors, there are all sorts of candle-power distributions which have been obtained to fit different conditions, as for example, the so-called "extensive," "intensive" and "focusing" forms of distribution, all of which have been designed to fulfill lighting conditions which it would have been impossible to produce or even know the requirements of without a proper knowledge of illuminating engineering. In fact such glassware is, as a rule, designed after the requirements have first been laid down in accordance with the principles of illuminating engineering. Take, for example, the case of a recent type of street reflector, in which, after a theoretical investigation it was found desirable to have a candle-power distribution such as shown in Fig. 1. Fig. 2 shows the actual curve finally obtained by the proper design of the reflector and lamp and is perhaps as good an example as could be used of the value of illuminating engineering in this

class of work. It is self-evident that new fields are being opened up from time to time by a study of the requirements through the aid of illuminating engineering. The same careful work is not only being done in the case of prismatic reflectors but also with other types; for example, in the case of a type of reflector designed to give an asymetrical distribution throwing the light up and down the street which was designed after a study of the requirements had shown the necessity for a very broad candle-power distribution in which the flux of light was largely confined to the street rather than spread uniformly into surrounding space. In the case of indirect lighting there is another example, where, by careful design, distribution curves have been obtained which will give maximum efficiency for this system of lighting,



Figs. 1 and 2.—Ideal and actual candle-power distributions.

As a matter of fact, the proper design of reflectors could hardly be said to exist were it not for a proper knowledge of illuminating engineering, and these two must of necessity go hand in hand. It is for this reason, probably, that the manufacturers of shades and reflectors were the first to recognize the value of illuminating engineering, and they have done all in their power to spread the art among the public as well as among those directly interested.

C. VALUE TO THE MANUFACTURER OF APPLIANCES.

Under this heading can be included all those devices which are directly applicable to the illuminants themselves. Thus, there are the fixtures used to support the illuminants and their shades or reflectors; the burners in connection with mantle gas lighting; the sockets for electric lamps; the tips for open gas and acetylene lighting, as well as numerous other appliances. The fixture

manufacturer has been, generally speaking, slow to recognize the value of illuminating engineering as applied to his art; but to-day the most progressive houses are recognizing its value and are accordingly taking advantage of it, much to their financial benefit, especially in commercial lighting. The lighting of a great majority of stores, office buildings and other commercial places is to-day being done by units which are properly supported by fixtures designed to give definite results. This is equally true of both gas and electricity. The result has been that within the last five years the types of fixtures for lighting such buildings and places have been entirely revolutionized, and those manufacturers who do not take advantage of the knowledge of illuminating engineering necessary to obtain the desired results, must of necessity fall behind in the race. Even in the case of more decorative plans where efficiency is of secondary consideration, a knowledge of illuminating engineering is beginning to tell. In the home to-day, for example, the educated customer is beginning to insist that his house shall not only be properly lighted from an artistic standpoint but also from an economical and physiological standpoint, and the manufacturer who can take advantage of these conditions is the one who will get the business. It will therefore be evident that a knowledge of illuminating engineering in the proper design of fixtures to fit the conditions at hand is also of value.

In the case of burners for mantle gas lamps the question of price is of secondary consideration. This is evidenced by the fact that the majority of the business of the country for this line is controlled by one company; this is due to the quality of its apparatus rather than a question of price. Such burners, being designed along scientific lines and with the ideas of illuminating engineering used in its broad sense, have become standard for this class of work throughout the country. The fact that the company above mentioned is employing illuminating engineering methods and is the foremost one in the gas field, fully bears out the point mentioned.

A similar line of argument might be used in the case of acetylene burners, sockets and other material directly used in the sup-

port of illuminants; but sufficient has been given here for the purposes in hand.

D. VALUE TO THE MANUFACTURER OF CONTRIBUTING APPARATUS.

The value to this class of manufacturers is indirect rather than direct, but that its value is great no one would deny. Thus in the incandescent electric lamp field the extension during the past few years into new fields has been tremendous, all of which means a larger demand for apparatus of all kinds. The manufacturer of the electric generator, the steam boiler and all the other necessary parts to a generating station,—conduits, wire, porcelain, and all the appliances necessary for the distribution of electrical energy, have been greatly benefited by the large increase in the use of electric energy, by reason of a more thorough appreciation of its advantages by the public, which have been largely caused by the correct use, due to a knowledge of illuminating engineering, either on the part of the customer or those responsible for the sale of the illuminants. That this is of great practical value is recognized by the great electrical jobbing fraternity of the country, who, when asked by a prominent manufacturer whether they would rather have a larger margin of profit and have the educational work in illuminating engineering by the manufacturer cease, or have their present margin of profit with the educational work in illuminating engineering continued. stated that owing to the large increase in sales of contributing apparatus as well as the direct illuminants and their accessories, they would much prefer to have the missionary work in illuminating engineering continued.

CONCLUSIONS.

It is seen from the examples cited above that illuminating engineering is of great benefit to the manufacturer of all sorts of apparatus used in connection with artificial lighting, either directly or indirectly, and the fact that large sums of money are being spent to further the knowledge of illuminating engineering is ample evidence of the correctness of this statement.

PRACTICAL VALUE OF ILLUMINATING ENGINEERING TO THE CENTRAL STATION.[1]

BY JOHN F. GILCHRIST.

The practical value of illuminating engineering to the central station is the value which a very high order of education on the part of those handling the selling end of any business give to that business.

When a person enters the shop of a large dealer in porcelain and china and meets a salesman who not only knows his stock and what is being manufactured throughout the world in his line at the present day, but is well educated in the history of porcelain and china manufacture, and knows all of the different wares, their values, their peculiarities; one whose taste is cultivated to the point of dependability, he is inspired with a confidence which assures him that whatever is purchased under the advice of this salesman will bear the criticism of a connoisseur, and he is quite likely to become a customer of that shop.

On the other hand, if a person enters another shop where there is an equally good stock and assortment of goods, and is taken in hand by an indifferent salesman who can only lead one to the counters and leave him to grope in the darkness of his own inexperience, he is more than likely to be so annoyed, disgusted and overcome with the feeling that he cannot depend upon his own judgment, that rather than take the chance of making a mistake he will defer his purshase or go where he can get good advice. By this experiment one can demonstrate the experience and results which will follow with a potential purchaser of electricity for lighting, when in the one instance he falls into the hands of the expert who has equipped himself with a thorough knowledge of illuminating engineering and in the other, he is waited on by the ordinary inexperienced solicitor generally found selling electricity.

In other words, illuminating engineering is simply a very high order of information and intelligence as to light, the quality,

[1] A paper presented at the Fourth Annual Convention of the Illuminating Engineering Society, Baltimore, October 24 and 25, 1910.

and quantities, and arrangement necessary to obtain the best results for given purposes.

There can be no doubt as to the very great desirability from the standpoint of their own interests, of the central stations fostering the development of illuminating engineering and the training of the young men in the industry to a thorough knowledge and appreciation of the fundamental principles of proper illumination.

Until within the past few years a comparatively small number of men in the electric lighting business have been impressed with the importance of this sort of intelligence and training, the attention of most of the best minds having been directed toward the development and operation of apparatus for the generation of electricity, and to the engineering problems which pertain to the transforming and the distributing systems incidental to the supply of energy to customers from a central station plant. It is only recently that, through the work of specialists advanced in their profession and the influence of the Illuminating Engineering Society and kindred organizations, intelligent attention has been given to the very important matters of utilizing the light produced, in the most proper, hygienic, and economical ways.

Under this new order, however, remarkable progress has already been made in the development of illuminants which are more economical and which are better adapted for various forms of lighting and the standard of artificial illumination has been increased more, perhaps, than the standard of any other modern product. To appreciate this fact fully, one who has been in the business for any considerable length of time has only to compare the illumination in the store of some conservative customer where five or six years ago he laid out a system of illumination in which he took great pride, and which has not subsequently been changed, with what he considers proper present day illumination in some similar store recently equipped.

The above simple observation will prove several things. It will prove the advance in the standard of illumination. It will prove to those who have looked on both installations as masterpieces of the period how much advancement has been made in the knowledge of illuminating engineering, although the

obtaining of this education may have been involuntary and by a process of absorption rather than through any premeditated effort and the old unchanged installation by its very rareness will prove to what an extent the layman has acceded to the compelling force of the times demanding higher standards of illumination.

It is in this point of the education of the customer that one of the great practical values of illuminating engineering to the central station lies. The progressive layman will rarely turn a deaf ear to reasonable views and advice tending toward better illumination. Very true, most users of electricity hesitate to increase their expense but the central station man has often heard the statement made by a customer somewhat as follows: "I believe in plenty of light. I am not satisfied with my lighting arrangements, although the cost seems to be all that I can stand. Can you not make some suggestion which will give me more light for what I am paying, or even a little more than I am paying? If I could get three or four times the amount of illumination for an increased expenditure of from 50 to 100 per cent., I would very gladly make the arrangement." This may seem to-day to be rather an impossible proposition, but it sounded more impossible ten years ago, and yet at the same price per kw.-hour for electricity, the customer's wish has in that period been more than met as the result of the great development in illuminants themselves and the greater intelligence in the placing of these illuminants.

The central station manager should wake up thoroughly to the fact that in the lighting end of his business what he should sell is an effective and useful illumination, and not merely electricity, but he cannot sell the former without the aid of representatives who are thoroughly well educated and up-to-date in matters of illumination, and in such representatives he has nothing more nor less than a corps of illuminating engineers, despite any prejudices he may entertain.

Leaving for a moment some of the direct advantages of illuminating engineering to the central station, there is an indirect, though none the less practical, advantage which should not be overlooked. One of the great difficulties in organizing a department for the sale of electricity for lighting purposes is the difficulty in obtaining and holding the services of men in these de-

partments who have had engineering training. Their inclinations are to belittle this important part of the business and to secure occupation in the departments of operation and construction of plant. This is undoubtedly due to the fact that they consider that these other departments offer better opportunity for the use and development of their technical knowledge, affording, in plain language, more interesting employment. They can hardly be blamed for holding this opinion under the old condition of things, when the obtaining of an electric light customer was more a question of legs than of brains. However, the development of illuminating engineering with all of the interesting problems and possibilities is rapidly demonstrating to this class of men that there is a great deal worthy of their brains and talents to be found in the scientific sale of illumination. Consequently the electric light companies are able to hold in their selling departments a class of men who are not only capable of getting good practical results, but who are abreast of the times and who are not losing any opportunities to put to practical use very promptly new ideas which are developing all over the world, and which are being reported weekly in the columns of the technical press.

The Illuminating Engineering Society has accomplished a vast amount of good for the central stations in the work which it has done up to the present time. Perhaps it has not received the hearty support of the central stations in the way that it should have done, but the work is only begun and it should feel only the greatest amount of encouragement for what it has accomplished and keep on in a larger way year by year. Central station managers must see their interests, and be shown them if they do not see them, and a larger number of the rank and file of the young men selling illumination must be secured as members of the Society and placed within the influence of its educational features.

A splendid advance has been made in the course of lectures which has been arranged to follow the convention of the Society, and undoubtedly a large number will take advantage of the opportunity offered, but unfortunately whatever this number is, it will be relatively small when the whole number of men in the business is taken into consideration. The

Society should consider some means of extending these benefits to a very much greater number of men engaged in the practical work of selling illumination than could possibly be gathered together at any one place. Results could possibly be accomplished by giving this form of instruction from several centers, or better yet, some correspondence arrangement, with examinations, etc., might be arranged which would insure the proper amount of individual work on the part of students.

With the proper stirring up, there should be no difficulty in providing the necessary funds for such courses of instructions, because, from the standpoint of the central station, there is no more practical work in the industry than that being done by the Illuminating Engineering Society.

DISCUSSION OF PAPERS BY SERRILL, LANSINGH AND GILCHRIST.

Mr. G. H. Stickney:—Mr. W. D'A Ryan, when he found he could not come to this meeting, asked me to represent him. While to-day no one doubts the commercial value of illuminating engineering to lamp manufacturers, central stations and others, the condition at the time when Mr. Ryan started was entirely different. At that time practically no attention was given to the lighting performance of a lamp and it was a very difficult matter to convince people that it was worth investigating or that investigations had any practical value.

The improvement in artificial illuminants and the increased knowledge regarding their right use has extended their benefits to all classes of people. To-day many processes which formerly required daylight are carried on at night and in the evening and throughout the dark winter days. Adequate illumination can now be provided in the large congested city districts where daylight is not available. Thus, all industries besides those connected with the actual production of light have been extended and benefited.

There is still another class of people who have not been discussed in the papers and who will derive a direct benefit from illuminating engineering, namely, the architects. The Illuminating Engineering Society should give a great deal of attention to the architects, both for their own good and for the

advancement of the art. There are a few architects who have, through contact with illuminating engineering departments of manufacturers and central stations, realized the value of illuminating engineering and taken advantage of it, but as a body the architects still fail to realize that illuminating engineering is essential to the best promulgation of their work.

Mr. E. B. Rowe:—In connection with the use of tables, forms and constants by commercial men, attention should be called to the need of constant activity on the part of the manufacturer to keep "short cut" methods and constants at the highest standard of accuracy. Mention should be made of the increased use during the last two years of simple methods of calculation, particularly the so-called "flux-of-light" method. In that method as commonly applied there are several errors. One is the dependence of the method on lamp efficiency. There seems to be a new method of applying these constants which will eliminate that error. By changing the "constants" to involve, instead of watts, the *total lumens* of the lamp, one can eliminate changes in lamp efficiency, and therefore have a method which will be independent of improvements in manufacture. This statement of course is applicable to gas illuminating engineering as well as to electricity.

Mr. H. L. Parker:—In the practical application of illuminating engineering, I, as well as many others, have had considerable trouble with electric contractors and gas fitters. It seems that there is a great deal of indifference on the part of the average contractor whether he employs a wireman or a gasfitter in placing the lighting installations which someone has taken the trouble to plan carefully. The manufacturers and the central stations, have organized illuminating engineering departments the services of which are open to the public. The public occasionally take advantage of these departments. Some one spends time in elaborate recommendations for the proper lighting and installation in a place, but when the plans reach the contractor, they are not carried out. Unless some compromise can be made between the plans and what the wire men actually do, the result is dissatisfaction to the customer.

Without discrediting the work of the membership committee,

I wish to remind them that there are now about 1,600 members, while there are over 5,000 central stations in this country, and there are about 7,000 electrical contractors. It seems to me there should be at least one member in each of the stations somewhat conversant with illuminating engineering principles.

Mr. E. L. Elliott:—As we have just heard, there are some 7,000 electrical contractors in the country. The electrical contractor is, by the very nature of his business, an illuminating engineer. In the case of remodeled installations he is generally the "first aid" that the customer or user turns to for information,—any work that can be done in connection with the organization of the electrical contractors, to create a greater interest in the subject of illuminating engineering would be excellent.

Mr. Norman Macbeth:—There is no doubt that every word in Mr. Lansingh's paper is important and true. I remember a few years ago meeting a manufacturer's sales manager who told me that he believed his company had a sales organization which would enable it to sell any kind of crockery by calling it a shade. I happen to know that that same manufacturer a short time afterwards lost several thousand dollars on one of those pieces of glassware which he tried to dispose of in the old way. The photometric curves were not what was desired and the sales organization was powerless in obtaining customers.

The point Mr. Serrill brought up about getting the salesmen into the Society is very important. There is no doubt that the salesman should become a member of the Society. He is the man who sells the lighting installation and is responsible for its success or failure. What the general salesman wants to know, as one of them remarked in one of the earlier meetings of the Illuminating Engineering Society, is how to get more business. If he is given this information there will be no difficulty in getting him interested in the Society.

Mr. B. C. Regar:—Mr. Serrill is to be congratulated for the very plain manner in which he has pointed out the usefulness of a knowledge of illuminating engineering to the commercial man, and the good to be derived by the company by having men thus qualified. I should like to mention a certain case which

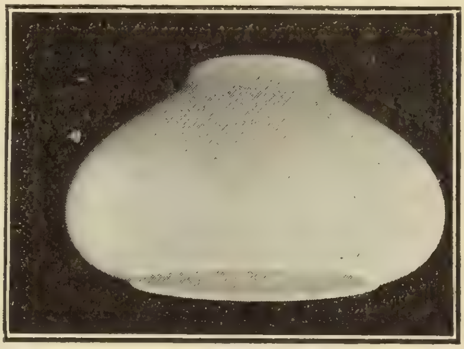
happened in the past few weeks. A large lighting customer in Philadelphia was interested in a change of lighting units and reflectors. The representative of a certain line knew that his line was good and good looking, but he didn't know why, nor did he understand the curves which had been sent him, and yet he secured the order, the reason being that other interests had aided him, and also because the man who had charge of the lighting was an engineer, and was able to grasp the advantages of the goods. Without reflecting on the representative or his company, it seems to me that this experience should point out to this man at once the necessity of his giving some of his time to the study of illuminating engineering.

A SCIENTIFICALLY DESIGNED STREET LIGHTING UNIT.[1]

BY HERBERT S. WHITING.

As the title of this paper indicates, the street lighting unit to be discussed represents a development made to meet the requirements of street illumination as determined by a scientifically conducted investigation. The results of the investigation were presented by Mr. Arthur J. Sweet before the Franklin Institute of Philadelphia in a paper entitled "An Analysis of Illumination Requirements in Street Lighting."

The requirements as thus determined indicate the necessity of a sufficient and uniform illumination; the avoidance of glare effects, which may be accomplished by the suppression of light



Figs. 1 and 2.—Prismatic reflector and opal envelope.

above an angle of approximately 65 degrees with the vertical; and a proper ratio of the distance between adjacent units and the mounting height—for entirely satisfactory results this ratio should not exceed four.

A successful street lighting unit must have incorporated in its design, in addition to the requirements of illumination, the features of efficiency, artistic appearance and practicability.

The unit which has been designed to meet these requirements consists of a prismatic reflector (as shown in Fig. 1) flanged to support an opal envelope indicated in Fig. 2, with a special fitter.

[1] A paper presented before the New York Section of the Illuminating Engineering Society on October 13, 1910.

The assembled unit is shown in Fig. 3. This unit is designed for use with a point source tungsten filament street series lamp, such as is being developed by several of the representative lamp manufacturers in this country. Very satisfactory results, however, may be obtained with 60-watt and 100-watt street series tungsten filament lamps, and fairly satisfactory results with multiple lamps. The units should be supported by standards from 12 to 15 ft. high, located from 60 to 75 ft. apart. In the case of a single row of standards along one side or the centre of the

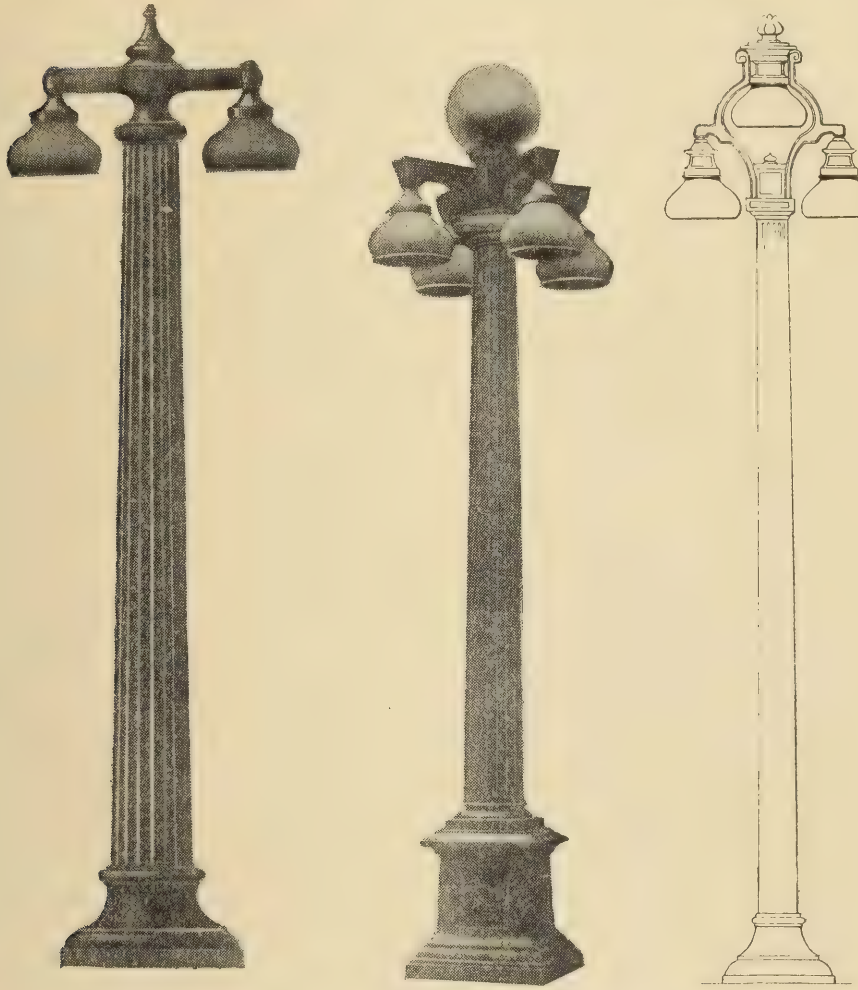
Fig. 3.—Street lighting unit without lamp.

street, or of two rows with units directly opposite each other, this spacing distance is the distance along the street; in the case of two rows of standards with units staggered, it is the diagonal distance across the street.

Particular attention is called to the recommendation for a mounting height some what greater than has commonly been used. This increase, however, represents one of the most recent developments in street lighting practice, and its desirability and practicability are evidenced by the fact that one, at least, of the most important street lighting standard manufacturers is prepared to furnish posts from 12 to 13 feet in height at no in-

crease in cost over the lower mounting heights which were formerly customary. Illustrations of typical standards are shown in Figs. 4, 5 and 6.

Sufficient illumination may be obtained by single light units for



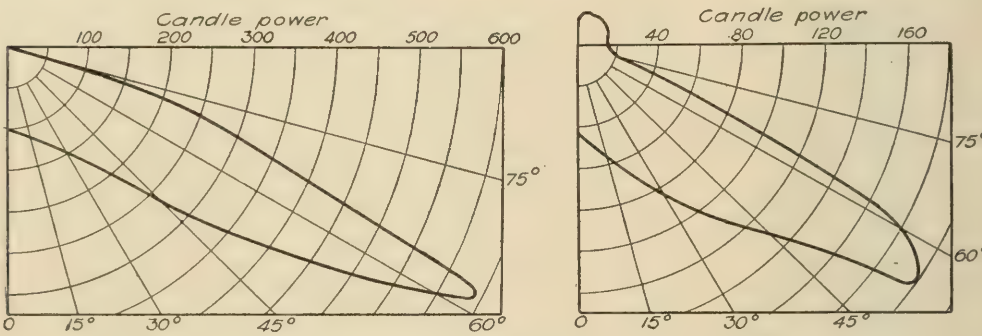
Figs. 4, 5 and 6.—Street lighting standards.

streets where a comparatively low intensity is required; to obtain a higher degree of illumination several units may be grouped on each standard.

In regard to uniformity of illumination obtained the candle-power distribution curve for uniform illumination when the ratio of the distance between adjacent standards and the mounting height equals 4, is shown in Fig. 7. This curve should be compared with that of the new street lighting unit as given in Fig. 8, and it will be evident that exceedingly satisfactory results may

be obtained if the ratio of spacing to mounting height equal to 4 is maintained. Inasmuch as the recommendations for the use of this unit allow a somewhat wider spacing, strictly uniform illumination will not be obtained. It is felt, however, that sufficient uniformity for all practical purposes will be obtained if the illumination at the point of maximum intensity does not much exceed four times that at the point of minimum intensity. This degree of uniformity is obtained, even with the present standard street series and multiple tungsten filament lamps, when the foregoing recommendations are adhered to.

One of the most important, if not the most important, features of this unit is the absence of glare. This is evident from an observation of the photometric curve, Fig. 8 which shows that there is practically no light above an angle of 65 degrees with the



Figs. 7 and 8.—Theoretical and actual candle-power distribution curves.

vertical. The small amount of light that is transmitted through the prismatic reflector is suppressed by the opal envelope, which is of such density that its specific brightness, or intrinsic brilliancy, is sufficiently low to cause no appreciable glare effect. Slight glare effect is produced with the standard lamps at present on the market, but this glare is practically negligible when compared with that produced by other light units which come anywhere near approaching the new unit in efficiency.

In addition to the suppression of transmitted light the opal envelope performs two other functions: First, it forms a unit presenting an artistic appearance, as an individual light source and allows sufficient light to pass through so that a particularly pleasing effect is produced by a row of light units; second, it protects the prisms from deposits of dirt, which in the pres-

ence of moisture would appreciably decrease the efficiency of the reflector—this is the most important of all its purposes.

The following table shows the comparative efficiencies of several types of street lighting units. The values given for efficiencies represent the ratio of the flux falling on the street to the total flux of the light units. It was assumed in determining these figures that the width of the street was 45 feet from curb to curb; distance from curb to property line, 10 ft; mounting height of unit, 12 feet.

Lamp	Equipment	Efficiency in per cent.
100-watt, 80 c-p. multiple tungsten ...	Bare	31
100-watt, 80 c-p. street-series tungsten	Bare	30
100-watt, 80 c-p. multiple tungsten ...	12-in. sand-blasted ball	28
100-watt, 80 c-p. multiple tungsten ...	12-in. opal ball	27
100-watt, 80 c-p. multiple tungsten ...	Prismatic reflector with opal envelope	51
100-watt, 80 c-p. point source series tungsten	Prismatic reflector with opal envelope	50
60-watt, 48 c-p. multiple tungsten ...	Prismatic reflector with opal envelope	52

A similar test on a radial wave reflector designed for street lighting showed an efficiency of 30 per cent.; as the glare effect produced by such a unit is considerable, the resulting visual efficiency, as compared with that of the above units would be much less than the figure given would indicate.

The new street lighting unit which has been described does, therefore, fulfill the requirements of sufficient and uniform illumination and avoidance of glare effect, with a very high efficiency of useful light flux. Moreover, it is of such appearance as to lend itself readily to appropiate designs for artistic street lighting standards. In addition it is adapted to, and its advantages may be obtained without departing from, the dictates of modern incandescent street lighting practice.

DISCUSSION.

Dr. C. H. Sharp:—The movement for better street lighting is one of the most marked movements in illuminating engineering at the present time. It has been to a very considerable extent simultaneous and synchronous with the coming of higher efficiency incandescent illuminants. I do not mean to say that

without the advent of the tungsten lamp there would not have been improved street lighting; but the availability of the high-efficiency incandescent lamp has probably done more than any other one thing to forward this movement. The improvement in street lighting has taken place along two lines; first in the efficiency and in the brilliancy of street illumination, and second, in the appearance of the illuminants. The installation of post lighting with tungsten lamps has marked the greatest improvement in the appearance of street illuminants that has as yet occurred. It has been accompanied with a much higher degree of illumination in the streets, but it has not as a rule been accompanied by a corresponding increase in the efficiency of that illumination. Tungsten lamps suspended in an opal sphere make a very beautiful form of illumination, but the efficiency cannot in the nature of things be very high.

The paper shows that the good appearance of a street lighting installation can be preserved and the efficiency of the lighting can be very much increased. In the street lighting reflector described the efficiency is improved in two ways—first by getting a larger percentage of the luminous flux on to the street surface and secondly by preventing deleterious glare. Now just how important the glare factor is I believe as yet to be a somewhat uncertain matter. The curves worked out by Mr. Sweet are most instructive and important, but I do not think they contain the final answer to that question. I do not believe that it is necessary in order to have good street illumination to cut off all glare. In fact, as was pointed out by a speaker at a meeting of this section in the Spring, in some cases the glare of the light reflected from the sidewalk reduces the sensibility of the eye for the perception of objects. In other words, it does not seem to be possible to cut off all the effects of glare, and it may not be necessary in order to get good street illumination and to get what is for practical purposes an absence of glare to go quite as far as the twenty-eight degree angle which Mr. Sweet has pointed out in his paper. A satisfactory minimum of glare may be obtained with a smaller angle between the horizontal and the illuminant. However, it is most commendable that in designing the reflector described the engineers have proceeded strictly along the theoretical lines which were laid down

as a result of Mr. Sweet's investigation; and they have not been satisfied with anything short of the perfection which is there indicated, so that in this latest form of street lighting reflector there is obtained a very happy combination of good appearance and of a reasonably high efficiency.

In a paper by Mr. Millar the importance of illuminating the roadway so as to enable objects on the roadway to be perceived has been pointed out. The reflector described works along these lines. It is very safe to say that any street which is illuminated with this new form of street lighting reflector, using the mounting height which is stated and the proper spacing of the lamps, would be a most excellently lighted street, and that the installation will be a very ornamental one both by day and by night.

Mr. W. H. Gardiner:—It seems to me that the reflector described represents work along exactly the right lines. It is along the lines of applying to street lighting the science of illuminating engineering which we have been applying to other forms of lighting such as in show window work, for instance, where the problem is to illuminate the goods instead of lighting the window. The equipment illuminates the street instead of putting lamps along it, which is a very different matter.

Mr. Henry Floyd:—Dr. Sharp's remarks on the effects of glare seem to me to be influenced largely by the way the light affects him personally; another person would be influenced in the way the light affected him. My personality being particularly susceptible to the glare effects, I was very much pleased with the author's explanation of the avoidance of these effects, and it seemed to me that he was not erring on the side of conservatism in the design illustrated. One who has walked along the Riverside Drive, New York and has experienced the effect of the tungsten lamps along the parkway there in his eyes, will appreciate that a lamp of the character described in the paper is a very marked improvement and a long step in advance in street lighting.

Mr. Albert Jackson Marshall:—Aside from the glare which the envelope removes, there are two further points to be considered, or one point divided into two classes, namely, its use in the residential district and its use in the down-town district.

I think it is very desirable to suppress light in those angles which would permit its falling too strongly in the windows of residences. In the business district there is a very practical side to the idea of suppressing light above, because if a great deal of light is permitted to go upward the sign business will be destroyed. This fact is very nicely demonstrated on Broadway, New York, around Thirty-ninth street where recently some flaming arc lamps have been introduced, the signs in that vicinity having been nearly destroyed. The effect that has given Broadway the name of the Great White Way is lost. There is a very good illustration of a most atrocious, not to say criminal, installation of arc lamps in St. Louis, where the sign business is absolutely killed, to say nothing of the trouble to the pedestrian's eyes.

In connection with the new street lighting unit, mention should be made of the question of color. I have an idea that white light, so-called, is not necessary or desirable for street lighting any more than it is for the home. I think that very much better results would be obtained if the ordinary arc lamp were used with a delicately tinted straw globe. Experiments could well be conducted with this unit using delicately tinted straw envelope in place of the white.

Mr. V. R. Lansingh:—The author states that the glaring effect with the unit described is entirely eliminated. Now this is probably not exactly true, for the reason that the eyelid is translucent. When a person passes underneath these units looking straight ahead, he will observe no effect of glare in the eye; that is to say, the light falling on the eye apparently will not give any glare effect. Nevertheless at the angle at which the maximum light strikes the eyelid, inasmuch as the eyelid is transparent, there will be more or less of a glare effect. This fact was brought out very nicely in a certain street installation, where by turning out the light suddenly a building which was entirely invisible before loomed up so that one could see it quite distinctly, thus showing that even under those conditions some glare effect is obtained, but of course far less than would be true if the lamp were not shaded.

Mr. Whiting has brought out very clearly the necessity for raising the lamps if anywhere near uniform illumination is to be

obtained. He mentions that with a ratio of four between the distance apart of the lamps and their mounting height good effects are obtained. I have seen an installation where the ratio was eight and permissible effects were obtained even then.

The opal envelope serves more purposes than one. In the first place, it reduces, of course, the intensity of light to the eye. In the second place it acts to protect the prisms from dirt. If a reflector of that kind were placed where it is exposed to storms and rains and then dust were allowed to fall on it, a considerable percentage of the reflection would be lost. The opal envelope acts as a dust protector, so that any dust or dirt which does get in between the tightly fitting cover and the opal envelope would be dry, and dry dust does not materially decrease the efficiency of such a reflector.

The envelope also serves another very important purpose in the marking of streets. That is to say, it lights the street as well as illuminates it. One other important point is that it is very easy to paint on the outside of this the name of a street or number, so that there is obtained all of the advantages of the ordinary opal ball in that respect.

A very clever device for individual lamps where it is desired to light side streets is a lantern effect which can be made very artistic, having an opal envelope and a reflector inside, but with the same candle-power distribution.

The author cites a certain case where 27 per cent. of the flux from an opal ball was within the effective zone. I simply want to call your attention to the fact that the actual tests check up with the theoretical results. With a spherical distribution of light which is found in the case of a dense opal ball, at 60 degrees on each side of the vertical, one-fourth of the total flux would be within that angle. The proof of this relation is very simple. The area of any zone is $2\ \pi \cos\ (\phi_1 - \phi_2)$ and the area of the sphere is $4\ \pi$. Since the cosine of 60 degrees is 0.5 the ratio of the two is one-fourth, so that the one-fourth of the total flux is within the sixty degree zone. The tests actually showed 27 per cent. within a little wider zone.

I want to call attention to one other possibility in the unit, and that is that the reflector itself can easily be designed to give an asymmetrical distribution. The light which goes towards

the sidewalk can be thrown up and down the street. With the glaring effect eliminated, with an asymmetrical distribution with lamps spaced on the sidewalk line, there would be a very good combination indeed. I might state, however, that with the new unit it is not necessary from the standpoint of the man who sits on his front porch to have an asymmetrical distribution because of the opal envelope, since the light, generally speaking, falls at the foot of the steps rather than at the top of the steps. However, from the standpoint of efficiency it may be desirable to use an asymmetrical distribution.

I had the pleasure recently of seeing an installation of these reflectors on a street and comparing them with the opal ball whose density was just sufficient to hide the filament of the lamp. The difference in the lighting effect on the street was very marked. It appeared to me fully up to the figures which showed a ratio of 3 to 1 on the street, and it seems to me that this is a step in the right direction of lighting our streets.

Mr. E. N. Hyde:—The dark spot between arc lamps placed at long intervals in suburban districts in all probability was one of the fundamental reasons for that old system of lighting which was conducted on what is known as the moonlight schedule. Moonlight in its intensity is low, but being general in its illumination it permitted more distinct vision than was possible to obtain with the lamps in use on account of the glare in the eye. For that reason lamps were turned off during the time that the moon was shining simply because they did not add to the illuminating effect but detracted from it. When streets or roadways are covered over with a heavy spread of snow considerable glare is noticeable from the bright spot immediately beneath the arc lamp. This effect when compared with the more equal distribution on the city street could be said to be an argument for even illumination. It seems to me that any step which will have a tendency to eliminate dark spots between light units and tend towards even illumination between lamps in the lighting of streets will be generally beneficial.

Mr. Gardiner:—In the case of the lighting of Broadway, St. Louis it seems to me that by brilliantly illuminating that street, the lighting company lost all its market for outline lighting, signs, and window lighting. It would be interesting to ascer-

tain the relative revenues per block or per mile, of a commercial street, a street given up to shops and stores, from street lighting, outlining signs and window lighting, and see how these figures check up in different cities where street lighting is handled in one way or another.

Mr. Lansingh:—I may state in answer to Mr. Gardiner that the figures for street lighting vary all the way from one to ten watts per running foot, which is not at all equivalent to the amount of light which the merchant uses under similar circumstances, that is in his show windows, etc.

Mr. Marshall:—In one of the most recent examples of show-window lighting in New York City the intensity varies between 60 and 100 watts per running foot, the idea being to use 60 watts where light materials are displayed and a 100-watt where darker materials are shown.

Mr. Preston S. Millar:—The street-lighting reflector described by Mr. Whiting, represents one of the few examples of a case where an illuminating engineer sets up a certain theoretical ideal and then starts out in practice to accomplish it and does accomplish it. Whatever should be said pro or con regarding the correctness of his theoretical conclusions, here he has made them in a practical way and the reflector is being put into commercial service. A good deal has been said recently about reflectors being used with incandescent electric lamps. Most of the street lighting in this country is with arc lamps, but they need the right kind of a reflector just as much as incandescent electric lamps do.

Mr. Lansingh:—The lighting unit described by Mr. Whiting has been tried out experimentally with inverted gas mantles, with practically better success than with the incandescent electric lamp by reason of the smallness of the source of light, which is the determining factor in the efficiency of this unit. In designing such a reflector for arc lamps difficulty is met on account of the shifting of the arc. Until that is overcome, it would seem almost impossible to design such a reflector.

ILLUMINATION AND ARCHITECTURE.[1]

BY WILLIAM COPELAND FURBER.

The lighted rush, animal and vegetable oils, tallow, wax, mineral oils and other carbonaceous materials have all in their turn, occupied the field as an aid to man as illuminants. These in turn have given way to better and more efficient means of illumination. The chief sources of illumination to-day are, of course, gas and electricity. Had the activities of man been confined to daylight alone, and had he gone to roost with the chickens, it is needless to say that his accomplishments would have been much curtailed.

The burning of midnight oil has always been synonymous with learning and with intellectual accomplishments. It might also be said that civilization would not have reached its present development without some means of extending the working hours of man. And yet it is to us, now, inconceivable that every advance in the art and science of illumination has had to fight its way through barriers of prejudice and entrenched opposition.

THE DEVELOPMENT OF GAS LIGHTING.

Before the introduction of gas, a material called "camphene," which was a mixture of alcohol and turpentine, was used for the purpose of illumination where oil, on account of its greasy nature, was not permissible. This substance was very volatile, and its vapor when mixed with air was very explosive. This material furnished the coroner with numerous subjects for inquests.

To review the history of gas briefly, it is said that the first record of anything like a careful examination of the properties of gas, artificial or natural, appears in the "Philosophical Transactions" for 1667, in a paper by Mr. Thomas Shirley. This gives an account of some experiments made in February, 1659, upon the gas issuing from a well near Wigan, England, wherein the author mentions that his attention was directed to what was

[1] A paper read before the Philadelphia Section of the Illuminating Engineering Society on April 15, 1910.

considered to be a spring "where the water did burn like oyle," and "did boyle and heave like water in a pot;" but on investigation he found this to "arise from strong breath, as it were a wind," which ignited on the approach of a lighted candle and "did burn bright and vigorous."

Up to this time, the names "spirit," "inflammable air," "vapor" and similar terms were used to designate the product in question, Van Helmont, one of the last of the old alchemists and one of the earliest and most important contributors to modern chemistry, being the only one to use the term "gas" or "gaz." This was about the year 1600. In 1786, Lavoisier applied the word "gaz" (gas in English) to all permanent seriform bodies.

The honor of the first application of coal gas to useful purposes is due to William Murdoch, who, in 1797, illuminated his premises at Old Cummock with gas, and the following year the factory of Boulton and Watts in Birmingham. Lebon followed shortly after in France. Winsor, a German, being impressed with the inventions of Lebon, set about introducing it, early turning attention to England. He lectured, gave demonstrations and wrote extensively.

Winsor at last succeeded in obtaining a charter, and the "Gas Light and Coke Company" was incorporated in 1808 and a charter obtained in 1812.

The company had a hard struggle for existence, and nearly went into dissolution. The employment of Mr. Clegg as engineer, however brought it out of its difficulties. There was violent opposition to the establishment of the company. In the event of its success, several branches of industry and commerce seemed doomed. For instance, the objectors said: "If this becomes successful, then our naval supremacy is gone, for at present we obtain principally our artificial light from the whale fisheries; these are the nurseries of our best sailors; therefore, if we destroy the one, the other must be affected; if the fisheries no longer exist, our navy must degenerate."

Mr. (afterwards Sir) Humphrey Davy considered the scheme so ridiculous that he asked if it were intended to take the dome of St. Paul's for a gasometer; to which Mr. Clegg replied that he hoped to see the day when gasometers would not be much

smaller. This hope was verified beyond his expectation. The external diameter of the dome is 145 feet, and before the death of Mr. Clegg in 1861, several gas holders had been constructed of larger size. That of the Imperial Company at the Hackney Road Station is 201 feet in diameter, and it may be of interest to note that the new holder of the Consolidated Gas Co. is 297 feet in diameter.

On December 31st, 1813, Westminster Bridge was lighted with gas. The new lamps were such an object of attention that, while the novelty lasted, the Bridge became a fashionable promenade. The lamplighters were so much startled at the new system that they refused to work, and Mr. Clegg for a few nights had to light the lamps himself.

In a book on gas lighting published in London in 1892, W. H. Y. Webber says that the earliest gas burners of which there are any record were designed to produce flames resembling those of the oil and tallow candles. He also says that it is quite possible to dismiss the problem of interior lighting and adopt some such rule of thumb as that lately expounded by W. H. Preece for the edification of the Royal Institute of British Architects, namely: that a 16 c-p. lamp at a height of 8 ft. above the floor will light a floor space 4 ft. square. It is hardly necessary to say that such a rule as this would not answer our requirements to-day.

When Maximilian was made Emperor of Mexico, the hall at the convention ball was lighted by candles. Wax candles had been ordered, but paraffine was substituted and the wax dropped down on the peoples' shoulders, but it probably did not spoil any garments on the shoulders of the ladies.

GAS LIGHTING IN PHILADELPHIA.

The earliest attenpt to secure a gas works in Philadelphia was made by Dr. Bollman on December 28, 1815. In 1826-27, Robinson and Long of Baltimore, made a proposition to the Philadelphia City Councils to erect a gas works; but it was not until February 14, 1833 that the Councils recommended the building of such works, and on February 3, 1834, the Councils authorized the sending of engineers to Europe to study the

operation of works then in use. The proposal met with great opposition. The dangers of fire and the great loss of life and property from explosions were pointed out. The inconvenience and danger due to the flames suddenly disappearing and leaving the streets and houses in darkness, the necessity of digging up the streets, and the fact that the gas pipes at the intersection of each square must come in contact with the water pipes were all dwelt upon.

The introduction of public gas supply was objected to by prominent citizens. On January 1, 1833, a protest was filed with the City Government, which, among other things, stated "We consider gas to be an article as ignitable as gunpowder and nearly as fatal in its effects."

John C. Cresson and others signed a paper declaring gas to be dangerous, and pointing out that if a fire occurred in a gas works it would result in blowing up the whole city. The city supply was started February 8, 1836. Private gas lighting, however, with insolated plants in the houses, was in use prior to this time, and in 1816, William Henry, a metalsmith on Lombard Street near Seventh illuminated his house with gas. This is said to be the first instance of house lighting from a private plant in this country, although it is also claimed that gas was used to illuminate the Bath House at Newport, R. I. on November 13, 1813. The gas used was "hydrogen gas produced with pit coal," under a patent of the improved gas lamp issued by the President of the United States to David Melville and Winslow Lewis. Similar systems were installed in a cotton factory in Watertown, Mass., and in factories in Wenscott and Arkwright, R. I. It is also said that Matthew Newkirk, whose house occupied the site on which St. George's Hall at Thirteenth and Arch streets formerly stood, was the first house that was lighted from the public gas supply in Philadelphia. In 1825 a writer in the "United States Gazette," now the "North American," called gas "unsafe, a trouble and a nuisance." It is true, however, that the first efforts to make gas gave a much more offensive product than modern methods give.

It is also claimed that the first building in Philadelphia to be lighted by gas was the old Masonic Hall on Chestnut Street west

of Seventh. Gas was made by distilling rosin, and the retorts and the gasometer were located in a separated building in the rear of the Hall.

Public Illumination by Gas: After the advent of gas lighting and before electric lighting appeared, it was customary to use perforated tubes with small jets of gas for outlining words, devices, etc. In this connection, it may be interesting to recall that "Jones' Hotel" was on the site of the present Bulletin Building at Penn Square and Filbert Street. On "Cable Night" which commemorated the successful laying of the Atlantic Cable, this building was brilliantly illuminated, for those days, by gas jets. On one of the porticos of the hotel the word "Europe" was outlined in jets. On the other portico was the word "America." Between the two was suspended a pipe in simulation of the cable. Occasionally the strong wind would blow out part of the illumination, so from a pictorial standpoint at least, the cable communication was frequently interrupted.

Before the introduction of electric spark ignition for gas it was usual to ignite the chandeliers and public buildings with a torch on a long pole. The jets on the large chandelier in the Philadelphia Academy of Music, it is said, were ignited at one time in this manner from the top gallery.

It is interesting, in tracing the progress of illumination, to note that as recently as 1879, after gas became an everyday affair, Dr. William Wallis gave a lecture in London at the Society of Arts upon gas illumination, in which he says, "We are striving too hard to light up our streets brilliantly. I do not see any necessity for lighting up the streets to such an extent as to make them equal to daylight. What we want is simply to see where we are going, to avoid being robbed at night, and so on. Therefore, I think it is a great mistake to strive to make our streets as light as they are during the day.

If Dr. Wallis should visit the "Great White Way," Broadway, New York, after dark, or Market Street, Philadelphia, he might think that his idea of what was sufficient had been greatly exceeded.

LIGHTING OF STREETS.

The lighting of streets considered from an architectural stand-

point or rather from the standpoint of the effect that the light of the street produces upon buildings, presents great difficulties. The lamp, to be effective for economical illumination, must be near the street surface, and such a position causes the reversal of all the shadows from mouldings, projections, etc., which have been designed with the thought in mind of the prime source of illumination being overhead.

It is interesting to study the shadows on buildings caused by the strong electric lamps placed at the usual lamp post heights. It is needless to say that the eye is accustomed by nature and long usage to expect to see the shadows cast in a downward direction, and our sense of proportions of architectural subjects is based on this expectation. When the shadows are reversed, the mouldings which were entirely satisfactory with the light above, lose their significance, and new shadows appear which cause the apparent proportions to be radically changed. It is, of course, impossible to design a moulding or projection which will have satisfactory shadows from opposite directions, and this is one of the artistic difficulties met with in considering the bearing of illumination on architecture in relation to street lighting.

In interior lighting, the position of the sources of illumination can sometimes be placed with the architectural effect of shadows in mind, but if the room is high and the sources of the light are low, the same difficulty appears.

Mouldings and reliefs for interior work are frequently studied with regard only to the shadows cast by the lamps at a conventional angle above, whereas, in some cases the lighting by means of reflected daylight or artificial light never affects the design from the standpoint at which it was studied. It is hardly necessary to point out that the latter method cannot be justified. The real truth is that architectural mouldings have been developed under conditions where overhead lighting was the only source of illumination. The lighting of streets with the sole object of illumination is altogether another matter, and a development along these lines has been rapid of late years, illumination of Market Street, Philadelphia, being one of the latest attempts in this direction.

High Pressure Incandescent Gas Lamps in Philadelphia:—The gas lamps used at Broad and Arch Streets, Philadelphia, are made of bronze, although other metals, such as copper or enamelled steel, would be perfectly satisfactory. Each lamp is equipped with two inverted mantles, each about 3 in. long and slightly larger than the diameter of the ordinary inverted mantle. Each burner consumes 11 cu. ft. of gas per hour, or each lamp 22 cu. ft. of gas per hour. The gas is supplied to the lamps under a pressure of 2 pounds per sq. in. by means of a blower directly connected to an electric motor. The lamps are ignited by means of pilot burners, which are constantly burning when the main burners are extinguished, and are extinguished when the main burners are in use.

The candle-power of the lamp, equipped as at present with a clear glass globe, is maximum at about 65° from the vertical; at this point it is about 900 c-p. The candle-power directly below the lamp is 450; the candle-power above the lamp is very low, owing to the upper construction. The mean lower hemispherical candle-power is 835; the mean upper hemispherical candle-power is 115; the mean spherical candle-power is 475. The minimum illumination on the sidewalk along the curb is about 3 foot-candles, while the maximum illumination on the sidewalk along the curb is about 6 foot-candles.

The installation in many ways is quite similar to high pressure installations in various European cities, namely, Cologne, Vienna, Berlin and London, the only difference being in the design of the lamps and compressor. The candle-power is about the same as most of the lamps used abroad although in Berlin, there are some new three-burner lamps giving from 4.300 to 4,500 candle-power.

CHURCH ILLUMINATION.

The various religious denominations express their ideals not only through the powers of the preacher, the character of the music, and form of the ritual, but also through the architecture of the buildings and the arrangement of the lighting which gives the best expression to their varying ideals.

In the unvarnished, unpainted interior of the Quaker meeting house no attempt is made, through the charms of architecture

or the beauty of decoration, or the seductiveness of the music, or by any artificially arranged scheme of lighting, to appeal through the eye or the ear to the emotions. Here only a shelter and a quiet retreat are offered in order that the mind may dwell in meditation on the Quaker ideal: that of the "Inner Light." This primitive simplicity should be compared with the non-ritualistic Protestant churches, which are evangelistic, and appeal through their preaching, and also accentuate the social side of their meetings. Here is found more attempt at decorative embellishment and here more attention is given to pleasing the senses through attractive surroundings. Here the illumination is general and perhaps brilliant, but without any symbolic significance.

In the churches with forms and ceremonies, from the High English church to the Greek Roman churches, the whole architectural scheme is calculated to impress awfully the worshipper with his own insignificance. The high vaulted ceilings, the vastness of the great bulk of the interior, and the feeling of isolation caused thereby; the stained glass windows radiating their dim religious light, the slow measured music, the Gregorian chant of the choristers, and the intoning of the solemn service, are all designed to impress themselves upon the worshipper through the eye and the ear. The subtleties of the art of illumination are here required to mark the "Stations of the Cross" and to centre the whole attention of the believer upon the Holy of Holies beyond the chancel rail, while, here and there, dimly burning, a lamp alone marks some sacred shrine of canonized saint where special pleadings may be made. Within the Holy of Holies, in the Catholic church, where formerly only towering wax candles shed their light upon solemn or festal occasions, now when the incense is rising heavenward, symbolizing the ascending prayers, and the priest desires to impress the worshipper with the presence of the Host, suddenly hundred of electric lamps blaze out with brilliancy and illuminate the central *theme* of their worship,—*the Christ risen.*

In speaking of the lighting of churches, it is well known to most architects that the lighting scheme of the average church leaves much to be desired. Chandeliers and fixtures are frequently placed without regard to their lighting effect or the shad-

ows they will produce. It would appear, in many cases, that after the building had been constructed, the thought has suddenly occurred to some one that the building was sometimes used at night, and then fixtures had been placed where space could be found for them.

THEATRE LIGHTING.

In the Elizabethan days, the stage was lighted by oil lamps. The lines were everything and the scenery and properties little or nothing. Contrast the realistic glow of the moonlight in one of Henry Irving's Venetian street scenes, with the Elizabethan theatre lighted by a few smoky lamps and the moon made of a cheese box lighted with a candle. Compare this method of lighting with the modern stage, with its electric appliances designed to create dawn, daylight, sunlight, the deepening shadows of night, the glow of the moon, and which permits the electric wizard to rival in his touch the Aladdin of old. The great powers of suggestion which the modern stage possesses and the effects produced, impressive and lasting as they frequently are, is created not only by the material of the stage fittings, and the power of the artist, in his word portrayals and his characterizations, but in that subtle atmosphere of light and shadow, or sunrise and sunset, or fire-light glow, which the electric illuminator has advanced to so high an art.

When in the balcony scene Romeo makes love to Juliet, every lover in the audience thrills with his own possibilities in that line, and he is influenced not so much by the tender words of Romeo, or the ingenious responses of the gentle Juliet, as by that exquisite mellow light of the amber moon which suggests the words of Pyramus to Thisby: "Sweet moon, I thank thee for thy sunny beams. I thank thee for shining now so bright, for by thy gracious, glittering streams, I trust to taste of truest Thisby's—sight" and lo, when the play is done, can you realize that it was electric illumination which produced the illusion?

Or recall some stormy night when the bleak wintry wind was howling outside and you were comfortably seated in a modern theatre looking at the beautiful scene in the woodland where the fair Parthenia and the Barbarian Ingomar were saying "two souls with but a single thought, two hearts that beat

as one," which forced you to remember some of your own successes or failures as an Ingomar, and after the curtain has fallen and you returned to the street, and the icy blast of the winter's night froze the fond words of the lovers in your ear, you woke up to the realization that it was magic of the electrician's art that transformed the crudities of the scene painter into a shaded woodland bower, and that the spring like glow which warmed the cockles of your heart, and also concealed the crows feet in the fair Parthenia's complexion, and shaded the angular form of the aged actress into the gentle roundness of a fresh young girl, was all an illusion, brought about by the skillful placing of the electric lamps.

In the theatre it may be said that architecture and illumination meet on common ground. The beauty of the architecture, and the color of the decoration would be as "sweetness wasted upon the desert air" were it not for the "bottled sunshine" of the electric lamp which dispels the darkness, touches up the high lights, softens the shadows, and reproduces on the stage, at will, all the wonderful chromatic values of sunshine and shade.

The New Theatre, of New York City exemplifies the highest development in the electrical art applied to the theatre. In the design of the electrical equipment, former precedents have been disregarded and new precedents have been established by which all future accomplishments in stage lighting will be measured. This theatre is designed as an opera house, theatre and concert hall, and in every detail is carefully studied out to meet the most exacting requirements and produce the greatest niceties of light and shade to a degree never before attempted The requirements for operatic performances make unusual and exceptional demand for lighting effects, which have been most generously met in this installation.

Beyond the most bewildering completeness of the facilities provided, the chief novelty, if the word may be used in such a sense, consists in the adoption of "distant control," which means that the question of lighting is now considered such a vital part of the effect to be produced that the switchboard operator occupies the most conspicuous position in the center of the stage immediately behind the foot-lamps. Here he is invisible to the audience behind a hood which corresponds in position to that

occupied by the prompter on the operatic stage. From this hood the whole of the auditorium and the stage is visible to the operator, and by means of the distant control he regulates all the lamps in the auditorium as well as all those on the stage, and it is possible for him to supplement the effect of one of them with the other, or subordinate the one to the other. It has been customary, heretofore, to have the dimmers and switches for the stage and auditorium placed upon the stage behind the curtain and operated by hand control. In the New Theatre, all switches and electric mechanism have been removed from the stage and placed in one of the basement apartments and there operated by motors and solenoids. The control board is placed directly beneath the front part of the stage behind the foot-lamps and is of such a size that a man can reach it with extended arms. From his station under the hood the operator can set any and all of the dimmer switches at any desired point, and the light can be increased or diminished at a speed ranging from two seconds to fifteen minutes. One need not be a stage manager to realize the unusual possibilities for lighting effects, such as sunset, sunrise, moonrise, the darkening approach of storm, etc., which such control affords. By double and triple circuiting of the fixtures in the auditorium the operator can control the illumination in the house to suit the character of the play, and he can also drive patrons to their seats by switching off the greater part of the lamps in the corridors as a signal that the performance is about to begin.

The stage itself is very extensive in all its dimensions, and upon it has been expended more thought and labor than perhaps any other stage in existence. The pit below the stage is 30 feet deep, and there is a clear height from the stage floor to the rig loft of 117 feet. The stage is also equipped with a revolving floor similar to an automobile turn table, which makes it possible to set four scenes at once, so that in shifting from one act or scene to another, it is only necessary to turn the stage to an angle of 90°.

In the borders, strips, foots and pockets, use is made of the four-color lighting scheme the colors being red, white, blue and amber. The borders and foots are arranged in four sections across the stage, each with four colors separately dimmed and

separately controlled. Each dimmer is arranged to stop at any one of the 15 points which represent the full range of the dimmers. The motion of each individual dimmer is also actuated by electric clutches which cut out any one of these 15 points. For each dimmer, a limit controller can be set to stop the dimmer at any one of the 15 points throughout its range.

The complete mechanism makes it possible for the stage operator to control any individual section, turning it on and off, dimming it to any required point at any required speed and in any combination. The extreme time limits at which the dimmers are operated range from two seconds to 15 minutes in passing from full bright to full dim. The arrangements of the master switches and the master dimmer switches makes it possible to set lamps for one scene while another scene is being enacted, it being necessary at the beginning of the next scene merely to throw on the master switch and the master dimmer switch.

SIGN LIGHTING.

The subject of sign lighting is one demanding immediate attention. There will doubtless be in a few years legislation to regulate the present unrestrained use of lamps on streets, buildings, etc. The public in the streets and tenants occupying adjacent properties are entitled to some protection for the often impudent use of the illuminated signs, to force upon their attention some article in which they may not have the slightest interest. The invasion of our privacy by such methods is not to be commended. Some years ago an ordinance was passed requiring the removal of all swinging signs on the south side of Chestnut Street, Philadelphia, which ordinance was observed until recently, but now the electric sign is making its presence felt in a very unpleasant way. These signs are, as a rule, ugly, and not only do they offend the eye, but interfere with the vistas on the streets and obstruct the public illumination. Something should be done to prevent our streets and building from becoming "Midways" of advertising, and while this is not strictly an architectural matter, its relation to architecture is a close one, and must be considered sooner or later.

ILLUMINATION OF BUILDING EXTERIORS.

The illumination of exhibition buildings provides, perhaps, the most spectacular opportunity for combined illumination and architecture. The Paris Exhibition of 1899 was probably the first notable effort in this direction with the Eiffel Tower as the "Piece de Resistance." The Chicago World's Fair found this method of illumination carried to a wonderful completeness. This method of illumination has now become so general, that conventions and celebrations are made the occasions for constructing purely ornamental architectural forms for the display of light; as for instance the Peace Jubilee, the Elks Convention, the G. A. R. Encampment, in Philadelphia.

The Philadelphia City Hall has now as part of its equipment lines and festoons of wires, upon which lamps can be strung upon festive occasions; such as New Year, etc. This method of lighting was given considerable study at the Pan-American, and the two worlds fairs; and at Festival Hall of St. Louis, many beautiful effects were produced by the fixed and projected lights. It would seem as if the architectural effect of this method of lighting is a legitimate subject for the architect to consider. The mere stringing of lamps on the outline of a building is not necessarily an artistic performance, and there is ample room for future study of this particular subject.

DISCUSSION.

Mr. K. A. Albrecht:—One of the most important points in Mr. Furber's paper was that in regard to street lighting and signs. It is my contention that as soon as a street is brilliantly illuminated with high candle-power arc lamps, the irregular shouting signs will disappear. In Europe the preference is for white light for street lighting. The yellow is used more for sensational effects (yellow newspapers) and also for foundries and factories on account of its penetrating power.

Mr. Albert Jackson Marshall:—The subject of design in lighting installations should not be confined solely to buildings of well defined periods of architecture, but should also be exercised in the most utilitarian sort of places, for instance, such as store lighting. It has been somewhat customary in the past to suggest

the same lighting installation for all stores, irrespective of their different usages and different treatments of decoration. Just because they were considered "commercial" and utilitarian" any thing was thought good enough provided it produced the required foot-candle intensity of illumination, the result being that most all stores one sees look alike, destroying absolutely all "individualism" or "character" and thus materially reducing the advertising value of the lighting installations; in fact, most of such installations seen border on a state of monotony, which eventually must give way to a saner treatment.

The carbon dioxide vapor-tube lamp possesses some distinct advantages which, to my mind, sooner or later, will be brought into actual use. Its color is perhaps the closest approach to daylight now available, and is, therefore, of considerable value where matching the colors, such as in silk mills, is of primary importance. Other uses to which I think the lamp will be put is that of outlining of buildings where its low intrinsic brilliancy will accentuate architectural lines without casting the rest of the building into dense shadow as is ofttimes the case where incandescent lamps are used.

I want to call attention to a detail in connection with the architectural design of lamp posts which may have escaped attention. I have noticed on numerous occasions lamp posts weighing perhaps a ton or more, equipped with frail, delicate ground glass balls, which even when an illuminant was not lighted in them, certainly did not present a thoroughly harmonious feeling with the posts. When a single lamp is used in the center of such a ball, the delicacy becomes the more evident and likewise the sphere is diminished, apparently, to the size of the light source; it appears as a spot of light in the center of the sphere, thus throwing out of balance the entire post. When two or more lamps are used inside of a ball and lighted, the points of light being unsymmetrically placed, not only the ball but the entire post is distorted and presents a most unartistic appearance. Ground glass used alone is not a perfect diffuser, neither does it materially re-direct the rays of light in useful directions. About the only thing to recommend it is its cheapness. It seems to me that when an expensive post is being erected a few more

cents could be expended for glassware which would be suitable for the condition.

With regard to arc lamps possessing great brilliancy, I wish to voice my sentiments as being most strongly opposed to the use of such lamps on the streets, unless their brilliancy can be modified to the extent of being acceptable to the eye and they are placed at reasonable height above the street level. There recently have been installed in Newark, N. J. quite a number of flaming arc lamps; in most instances they are placed at such a height above the sidewalk that one is about blinded in attempting to walk along the streets. I think that such usage is almost criminal, and sooner or later they will either be removed, or placed at such positions as not to be injurious to the eyes of those who pass by. It might be of interest to some to learn that a bill is now being prepared by the New York Legislature designed to eliminate such usage as I have referred to and it seems to me that before allowing senators who know nothing about light to tell us how to use light, we should do something ourselves.

As regards color, I disagree with the previous speaker that the white light is the best color for all classes of work, especially street lighting. I am under the opinion that the quality of light obtained from the ordinary so-called "yellow flaming arc lamp" is preferable to that obtained from the "white" flaming arc lamp. In the first place, the yellow light more deeply penetrates fogs and smoke, secondly, it is more acceptable to the eye, and thirdly, it gives a warmer tone to the streets than the cold, hard effect created by the white light. In fact, I have on previous occasions advocated the use of lightly tinted straw opalescent globes on enclosed carbon arc lamps in place of the white opalescent.

Mr. J. D. Israel:—Mr. Furber thinks, or seems to think, that electric signs should be tabooed and we should have less of them. I think we should have more of them. We court the criticism of the architects and designers, and we ask their help and aid in getting out more artistic designs. In some Southern cities, a permit for the erection of electric signs carries with it an obligation to keep that sign in use until a certain hour of the night, which may be 11 or 12 o'clock, according to the particular town. The idea is that if permission is given to erect such a sign,

it must help to illuminate the streets, and give the town a Metropolitan air.

Mr. W. J. Serrill:—I am disposed to agree with the opinion that a yellow light is to be preferred to white in many places. Consider two lamps giving the same candle-power, one white and one yellow; the white always seems to be the brighter. Many people in stores and other commercial places prefer a white light, because it seems to be brighter and more brilliant than the yellow light of the same candle-power. However for residence use and for interiors used for social purposes, I think that the satisfactory light is somewhat yellow.

Mr. Albrecht:—While it is true that yellow gives to the eye a temporarily pleasing effect, I maintain that yellow fatigues the eye more quickly than does white. White being a neutral color is the least tiring, especially so as the eye is accustomed to white sunlight—the yellow of the sun set, also the violet or green or any other soft color produced by clouds of different density surrounding the sinking sun please the eye for a while, because like all our senses it welcomes a change and the whole physical system being tired enjoys the decreased intensity of illumination which hammered on its nerves all day.

Materially decreased intensity compared with sunlight for night illumination is undoubtedly desirable, but there is no question that well diffused white light is the most natural. The change which the eye needs we can get from the colored objects illuminated by white light; to study and provide this change of color is one of the architect's functions—he can make a room either enjoyable or tiresome and monotonous by proper attention to, or disregard of, colors in his decorations.

Mr. Norman Macbeth:—The question of the color of light—yellow against white—has brought out much discussion. Investigation by Dr. Ives has developed the fact that incandescent gas mantles approach closer to white light standards than any of the electric incandescent lamps, yet more fault has been found with incandescent mantle lamps in residence work than with other lamps which cannot by any method be conceived as giving white light. It is generally admitted that we have sources which are satisfactory for matching colors, and that is about all we

want white light for. I think the white light is entirely a matter for color process photo-engraving and color matching, where one must have a white light or a light containing all the colors to get results.

Bringing in the architectural features, as it does, this paper is extremely valuable. We have had some trouble to get the architects and decorators on record and I believe that when we do, there will be less room for disagreement. Judging by the very able papers so far presented before this society on these subjects, I do not think it will be more than a year or so before we have better understanding which will be mutually advantageous.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. V. DECEMBER, 1910. NO. 9

MINUTES OF COUNCIL MEETING.

DECEMBER 8, 1910.

The Council met in the general office of the Society on December 8. After the minutes of the previous meeting were approved, a report of the secretary on the financial and the membership status of the society was read and accepted.

President E. P. Hyde reported orally for the Lecture Committee that the final report of that committee had not been prepared because they had further duties to perform. These he said would be completed shortly and the report would probably be ready for the next meeting. He added that the work of publishing the recent lectures on illuminating engineering by Johns Hopkins University was in progress.

Mr. L. B. Marks, chairman of the Finance Committee, submitted the November vouchers aggregating $4109.20, which the committee had approved, and a statement of the expenses incurred by the Society in connection with the recent course in illuminating engineering at Johns Hopkins University. The Secretary was directed to pay the vouchers and to transmit the statement of lecture course expenses to the University.

The final report of Mr. V. R. Lansingh, chairman of the 1910 Convention Committee was accepted and placed on file.

To count the ballots of the current election of officers, Dr. C. H. Sharp, was appointed chairman of a committee of five. Messrs. Albert J. Marshall, H. Thurston Owens, E. F. Tweedy and Dr. A. H. Elliott were named as the other members of the committee.

Preston S. Millar, General Secretary, was appointed a committee of one to prepare the report from the Council to the Society to be presented at the annual meeting on January 13, 1911.

The election to membership of thirteen applicants, and the delegation to a committee for consideration of the adoption of a code of symbols inaugurated by a sister organization were among the other business transacted. Finally the Society's procedure in releasing its papers to the technical press and the policy of excluding from the TRANSACTIONS all trade names were each discussed at length.

Those present at the meeting were, Dr. E. P. Hyde, President, Dr. A. S. McAllister, Dr. E. B. Rosa, W. Cullin Morris, Treasurer; L. B. Marks and Basset Jones, Jr.

SECTION MEETINGS.

CHICAGO SECTION.

The regular monthly meeting of the Chicago Section was held at noon on December 15, in the Great Northern Hotel, being preceded as usual by a luncheon. John M. Bryant, assistant professor of electrical engineering, and Harry Gray Hake, instructor in electrical engineering, University of Illinois, presented a paper on "Comparative Costs of Producing Light with Different Illuminants." This paper embodied a comparison of thirty-one types of electric illuminants and ten types of gas, acetylene, kerosene, gasoline and alcohol illuminants. The basis of comparison was the cost of various rates for energy, gas, oil, etc., of producing 100,000 lumen-hours, maintenance being included. The paper was discussed by Messrs. Ward Harrison, Albert Scheible, C. M. Oxford, T. R. Beebe, T. H. Aldrich, A. L. Eustice, Chairman F. J. Pearson, Mr. Hake and Prof. Bryant.

At the meeting to be held on January 12, Mr. A. L. Eustice, of the Nernst Lamp Company, will present a paper on "Luminous Efficiency," which will review and discuss a paper on the same subject presented before the Society by Dr. Herbert E. Ives some time ago.

NEW YORK SECTION.

Two papers were presented at the meeting of the New York Section held in the Engineering Societies Building on December 8. A paper by Prof. Edward L. Nichols, of Cornell University, entitled "Some Notes of the Early History of Standards of Light" was presented in abstract by Mr. Albert Jackson Marshall. This paper appears in the present issue.

Mr. Bassett Jones, Jr. presented a paper entitled "The Lighting of the Allegheny County Soldiers' Memorial." This paper was discussed by Messrs A. J. Marshall, Henry Hornbostel, G. H. Stickney, J. B. Taylor, L. K. Comstock, E. Ellinger and Bassett Jones, Jr.

At a meeting to be held on January 12, Dr. Nelson M. Black, Milwaukee, Wis., will present a paper entitled "Artificial Illumination as a Factor in the Production of Ocular Discomfort." Dr. P. W. Cobb, Physiologist of the National Electric Lamp Association, Cleveland, Ohio, will read a paper entitled "Physiological Points Bearing on Glare." Mr. Paul Bauder, of the National Electric Lamp Association, will present a paper entitled "Reflection Coefficients." The photometry of mercury-vapor lamps will be treated in a paper by Dr. J. C. Pole, of the Cooper-Hewitt Electric Company.

At the February meeting Mr. Bassett Jones, Jr., will read a paper entitled "The Polar Curves of Finite Line and Surface Sources," and Mr. Henry Hornbostel will lead a discussion of the subject "Light and Architecture."

NEW ENGLAND SECTION.

At a meeting of the New England Section held in the Edison Building, Boston, on December 12, Mr. C. A. B. Halvorsen presented an illustrated paper entitled "The Evolution of the Arc Lamp."

PHILADELPHIA SECTION.

A meeting of the Philadelphia Section was held on December 16, at which time a paper entitled "The Lighting of a Large Stable Building" was presented by Mr. L. B. Eichengreen.

SOME NOTES ON THE EARLY HISTORY OF STANDARDS OF LIGHT.[1]

BY EDWARD L. NICHOLS.

The year 1884 is a convenient epoch at which to close what may be termed the early history of photometric standards. In that year, for the first time, the condition commonly recognized by photomotricians as essential to the satisfactory primary standard of light; that is, the maintenance of a substance of definite composition in a constant and reproducible state of incandescence, was reasonably fulfilled by means of the amyl-acetate lamp of von Hefner-Alteneck.[2]

In 1884 likewise the first international agreement upon a standard of luminous intensity was reached by the adoption of the violle by the Paris conference.

These notes, for which no claim of completeness is made, deal with the period prior to 1884.

THE CANDLE.

The beginnings of photometry were astronomical. Even before the time of Bouguer (1729), who is commonly regarded as the father of the science, attempts were made by Huyghens to estimate the relative brightness of the sun and of the fixed star Sirius. He expressed the intensity of the star in terms of the portion of the sun's disk which when viewed through the telescope would present a corresponding appearance. Bouguer[3] estimated the intensity of sunlight and of moonlight directly in candle-power and he seems to have regarded the candle as the most convenient and obvious photometric standard. He did not go further in designating what a standard candle should be than to speak of carefully selecting those that were of the same size. Lambert[4] (1760) also used candles in his photometric experiments.

[1] A paper presented at a meeting of the New York Section of the Illuminating Engineering Society, December 8, 1910.

[2] As to the validity of the claims of the advocates of the Hefner lamp, it is only necessary to refer to the recent findings of the photometricians of the United States Bureau of Standards concerning its remarkable constancy and reproducibility.

[3] Bouguer: Traité d'Optique, p. 4, et seq.

[4] Lambert: Photometria.

Rumford[5] (1794) went further than his predecessors. In his description of his improved photometer he says "To fill the important office of a standard of light with which all others are compared, I have chosen a wax candle of the first quality, just eight-tenths of an English inch in diameter and which when burning with a clear and steady flame has been found to consume very uniformly 108 grains Troy of wax per hour."

Rumford who deserves to be acclaimed as the *first of illuminating engineers* was engaged at this time in the construction of various public institutions for the Bavarian government. As a part of this work he attacked the problem of artificial lighting in a truly scientific spirit. He investigated all the existing sources of light, recognized the superiority of lamps of the Argand type (which had been invented in 1784) and devised multiple wick burners of 50 candles or more. It was for the study of these light sources that he perfected the shadow photometer of Lambert which became in his hands an instrument of precision.

It was in planning the Houses of Industry for the poor in Mannheim and Munich that the problem of adequate lighting was forced upon his attention. "In lighting up these spacious establishments" he says "I first learned to know how much room there was for improvement in the art of illumination."

How well Rumford appreciated the need of the scientific method in illumination is clear from the following quotation.

"What vast sums are expended in dispelling the obscurity of the night in every part of the world; and yet in what a deplorable state is the science which ought to elucidate all the details of that important operation. How is it possible to labor with any prospect of success to improve the methods employed in illumination so long as we remain so perfectly ignorant respecting the nature of light." This was written at a time when Rumford was busy devising experiments to overthrow the emission theory of light and the caloric fluid theory of heat.

Rumford had no illusions as to the reproducibility of the candle in any broad sense. He sought only a reasonable constancy of standardization for his own experiments and to secure

[5] Rumford: Life and Works, Vol. IV, p. 187.

this selected in advance his stock of candles which he hoarded carefully; realizing that on replenishing his stock he would not be likely to be able to duplicate them. He found Argand burners to afford greater steadiness than the candle but not to be depended upon from day to day without calibration. He therefore used an Argand lamp as a secondary standard, comparing it before each set of observations with the candle and using the latter only to check the performance of the lamp.

The British standard candle is usually spoken of as the oldest of such standards and this is doubtless true so far as legalized standards are concerned. It was defined by parliament in the Metropolitan Gas Act of 1860 as a standard spermaceti candle 7/8 of an inch in diameter and burning 120 grains in the hour.

Candles were, however, employed in England for photometric purposes at a much earlier day. Murdoch, the Cornwall mine owner, who was the first to make coal gas in Great Britain and who lighted his home and offices in this way as early as 1792 is said to have used tallow candles in gas-photometry in 1808.[6] His standards weighed six to the pound and consumed 175 grains per hour.

Leslie,[7] in his photometric work adopted the wax candle as his standard.

The German candle or Vereins-kerze appeared more than twenty years after the British candle in 1882. It was a paraffin candle 20 mm. in diameter and having a flame-height of 50 mm. and was the result of *fourteen years of labor* on the part of a commission of the Union of Gas and Water Engineers. This was a case, where, to turn an old saying about, *the candle was not worth the game;* for in spite of the long continued painstaking investigations of which is was the product it was but a slight improvement over the British candle and the same may be said of the other German standard known as the Munich candle. The latter was a stearine candle 23 mm. in diameter at the base, 20.5 mm. above and 310 mm. long. The normal flame-height was 52 mm. It attained local application as being temporarily the

6 Dibdin: Public Lighting by Gas and Electricity, p. 34.

7 Dibdin: l. c.

accepted standard in an agreement between the city of Munich and the manufacturers of gas.

The star candle of France had a much earlier and less pretentious origin. About 1830 DeMilly[8] discovered a cheap method of separating stearic acid from the glycerine and other substances in fats and in partnership with Motard he established a factory near the Barrière de l'Etoile; whence the name bougie de l' Etoile. Peclet[9] who tested the first products of this factory in 1830 found the candles to burn 10 gms. an hour and to equal 1/7 of a carcel in brightness. Palaz remarks that such candles are no longer to be found in France, the best not giving more than ⅛ of a carcel. In England on the contrary according to Heisch and Hartley modern candles (in 1884) were giving more light for the same consumption of spermaceti than was formerly the case.

The fourteen-year campaign of the German commissioners who brought out the Vereins-kerze is only one example of the incredible amount of work that was done in the attempt to make of the candle a satisfactory photometric standard and to determine, what from the very nature of the case is indeterminate, the exact relations of the various candles to each other and to other photometric standards. And yet it was only necessary to substitute for the eye a suitably constructed bolometer and a quick acting galvanometer of sufficient sensitiveness and with such an instrument to record the life history of any candle, as was done by C. H. Sharp and the late C. P. Matthews in 1896, in order to demonstrate once for all the worthlessness of such sources of light as photometric standards.

I venture to reproduce from the report of a Committee of the Institute of Electrical Engineers, in which the work just mentioned appeared,[10] diagrams illustrating the typical behavior of the British standard candle and the German candle burning under the best conditions these skilled photometricians were able to secure. (See Figs. 1 and 2). That the vagaries exhibited in these curves were not due to any fault in the method may be

[8] Encyc. Britt., 9th Edition, Vol. IV., p. 802, gives the date as 1831.

[9] See Palaz: Photometric Industrielle, p. 107.

[10] Nichols, Sharp and Matthews: *Trans. A. I.E.E.*, Vol. XIII (1896).

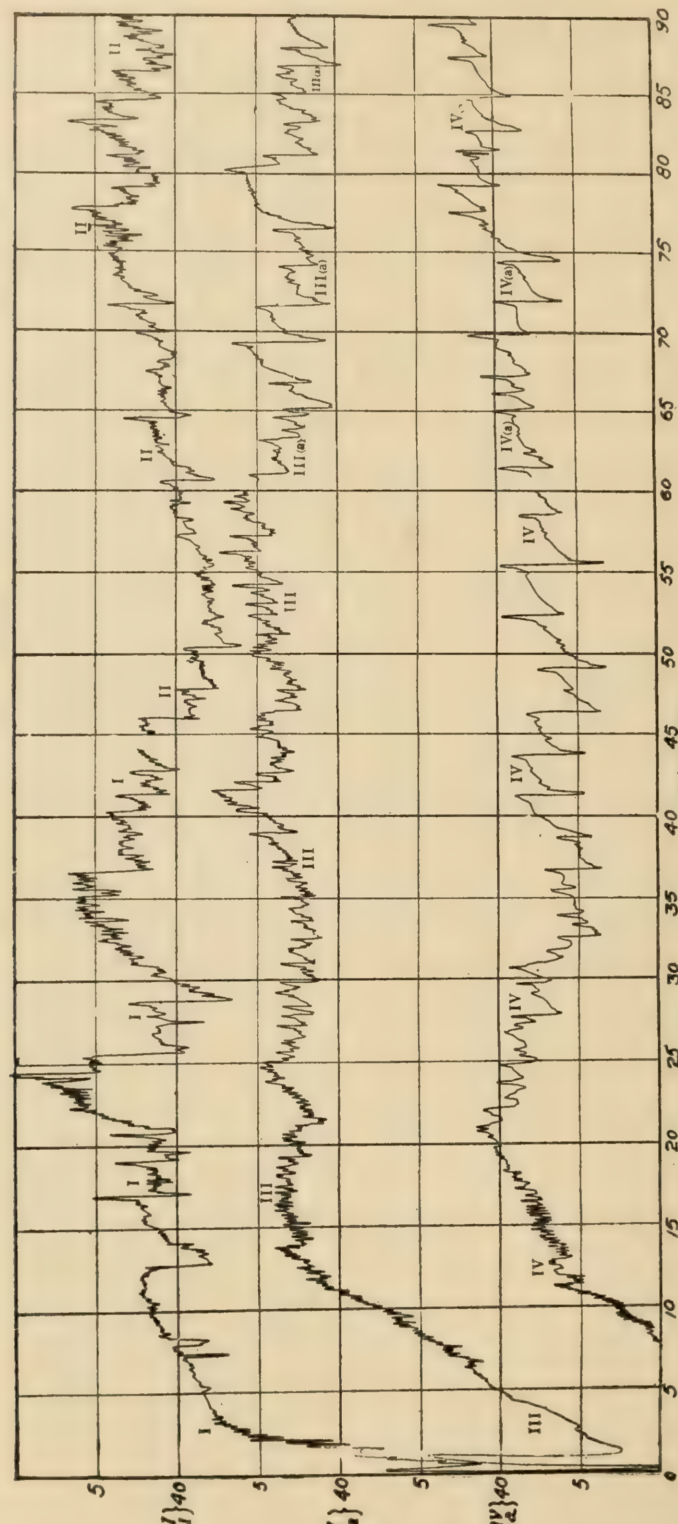


Fig. 1.—Variation in light output from the British candle.

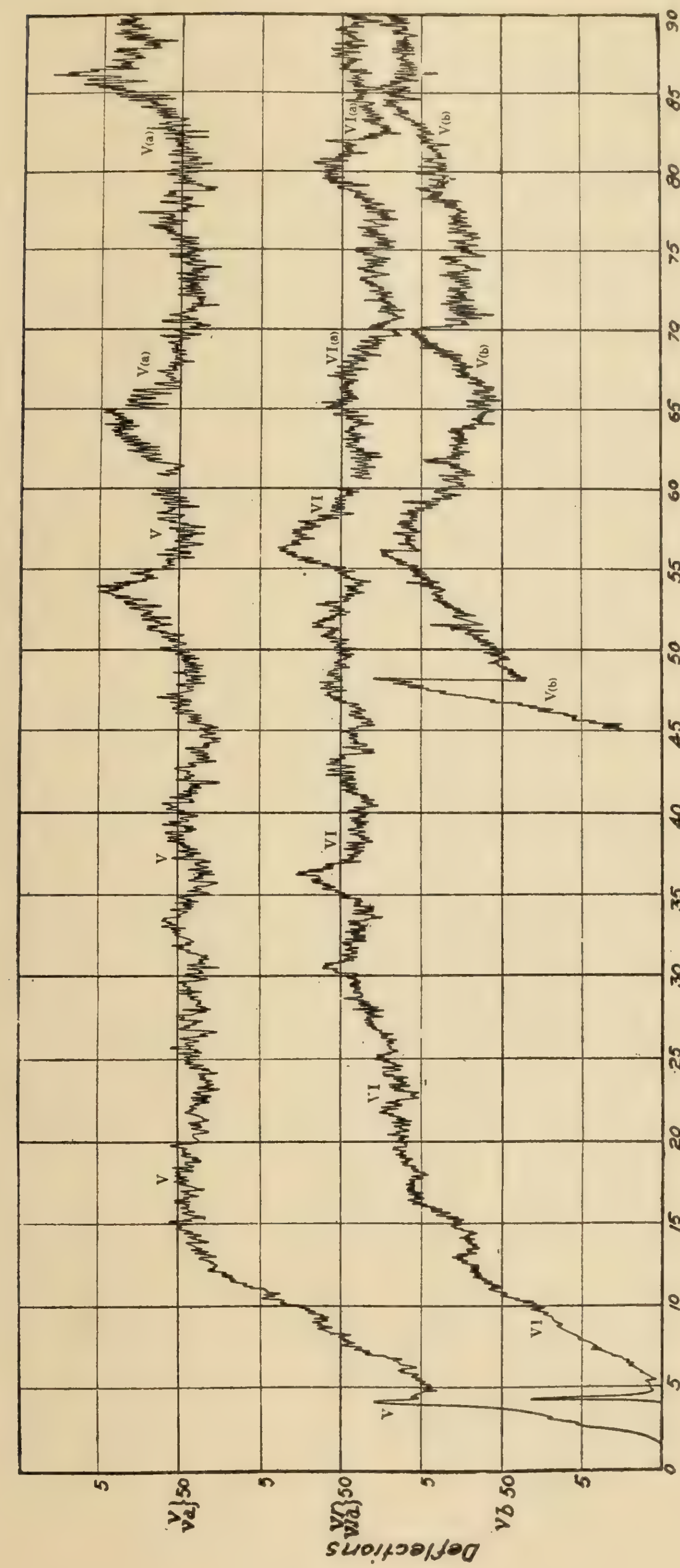


Fig. 2.—Variations in the light output from the German candle.

seen by comparing them with the corresponding curve for the pentane lamp (Fig. 3). The latter shows the gradual creeping up of the flame and the amenability of the lamp to readjustment as shown by the approach to a horizontal line which follows the second break in the curve.

With such evidence of the utter unreliability of the candle as a photometric standard it is easy to understand the discrepancies of the early attempts to reach some common ground and to bring the various candle standards into accord. The long continued and laborious efforts of English, German, Dutch and French photometricians in this field is a monument to the extraordinary

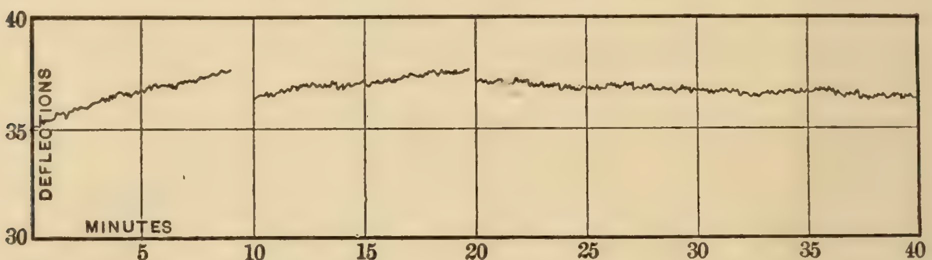


Fig. 3.—Variation in the light output of the Harcourt pentane lamp.

conservatism of the human race and to its fondness for clinging to things of the past however imperfect.

THE CARCEL.

This source of light, which is a modification of the oil lamps with central draft invented by Argand, was devised by Carcel and Carreau in 1800. It does not appear to have been originally intended as a photometric standard but for general domestic service.

Argand's[11] original lamp was described in February 1784 and it revolutionized the artificial lighting of the period. Some years later Lange modified the glass chimney by adding the contraction at the base of the flame. Carcel's contribution consisted in the mechanical device for keeping the wick uniformly flooded with colza oil and this added greatly to the steadiness and reliability of the lamp.

In the ninth year of the French republic (1801) we find it recorded that "Citizen Guyton reported on the mechanical lamp

[11] *Journal de Physique*, Feb., 1784, p. 59.

of Carcel and Carreau." "This lamp," he declares "is designed to add a new degree of perfection to lamps, with central draft as regards intensity, economy and convenience for daily use."[12]

The Carcel lamp owed its introduction as a standard to the labors of Arago and Fresnel. These eminent men of science were for many years engaged in the improvement of the light house service of France. In 1822 Fresnel in his memoir *On a New System of Coast Lights*[13] used the carcel as the standard in terms of which to define the power of the special oil lamps with several concentric wicks which were being introduced into his light houses. One of these had an intensity of seventeen carcels.

Arago and Fresnel also made an extensive study of the performance of illuminating gas with the idea of installing insolated gas plants at some of the more important light houses and of substituting large gas burners of the Argand type for oil lamps. In this study they likewise used the carcel as a photometric standard and when in 1845 an agreement was drawn up between the government and the company supplying street gas in Paris they specified on behalf of the city the performance which was to be demanded in terms of the carcel.

In 1856 complaints of the poorness of Paris gas led to the appointment of another commission consisting of Dumas, the chemist, and Regnault, two of the most illustrious experimenters of their time. They made further detailed studies of the Carcel lamp, determined the effects of wick-height and of the position and diameter of the contraction of the chimney and established standard conditions for its use. They specified 42 grams an hour of colza oil as the normal consumption having found this the amount which gave the best results. They said frankly that it is difficult to indicate in a general manner the conditions under which the Carcel lamp will give a determinate and constant effect, that two lamps having the same diameter of wick and the same capacity will differ in the consumption and in brightness and that the temperature of the lamp, the duration of burning and the amount of oil in the lamp will affect the intensity of the flame. They found that before using the Carcel lamp as a standard it

[12] Annales de Chimie et de Physique, Vol. XXXVIII, p. 135 (1801).

[13] Fresnel: Oeuvres Completes T, III.

was necessary to determine experimentally the conditions under which *it individually would give the greatest constancy of performance.*[14] In spite of these difficulties Dumas and Regnault drew up official specifications for a standard Carcel lamp to be used as the reference standard in testing the gas of the City of Paris. The following dimensions are given:—

STANDARD CARCEL LAMP.

	mm.
Exterior diameter of burner	23.5
Diameter of interior air tube	17.0
Diameter of exterior air tube	45.5
Total height of chimney	290.0
Distance of contraction from base to chimney	61.0
Diameter at level of contraction	47.0
Diameter at top of chimney	34.0
Thickness of glass of chimney	2.0

Wick to have 75 strands and to weigh 3.6 grams per length of 10 cm.; wick to be kept in a desiccator with quick lime and a new one employed at each lighting; the colza oil to be purified and the wick to be adjusted until the rate of combustion is 42 grams an hour.

The carcel thus became the legal standard for Paris and indeed for all France. Its merits were violently contested by English and German photometricians but continued to be so warmly advocated by those who were long accustomed to its use that at the first sitting of the International conference in Paris in 1881 it was adopted as the temporary practical unit pending the establishment of an absolute standard.

PLATINUM STANDARDS.

The first definite suggestion of the use of incandescent platinum as a standard of light was made by J. W. Draper in 1847 in his classical memoir on the temperature at which incandescence begins and on the development of the visible spectrum with further rise of temperature.[15]

Draper determined the temperature of a strip of electrically heated platinum by measuring its elongation. He says in the concluding paragraph of his paper:—

[14] Audoin and Berard: Annales de Chimie et de Physique, IV, Vol. LXV, p. 423.

[15] Draper, J. W.: *Am. Jour. of Science*, (2), Vol. IV, (1847).

"Among the writers on Optics it has been a desideratum to obtain a light of standard brilliancy. A surface of platinum of standard dimensions raised to a standard temperature by a voltaic current will always emit a constant light. A strip of that metal one inch long and 1/20 of an inch wide connected with a lever by which its expansion might be measured would yield at 2,000° (F) a light suitable for most purposes. Moreover it would be easy to form from it a photometer by screening portions of the shining surface. An ingenious artist would have little difficulty in taking advantage of the movements of the lever in making a self acting apparatus in which the platinum would be maintained at a uniform temperature, notwithstanding any change taking place in the voltaic current."

Forty years later the present writer[16] in a more detailed study of the visible radiation as a function of the temperature made use of the expansion of the metal as a criterion of its state of incandescence, although quite without reference to its use as a photometric standard, and he is still of the opinion that this affords the simplest indication and one which is much less subject to variations on account of the impurity of the metal etc. than the measurement of the electrical resistance.

In 1857 Friederich Zoellner[17] the German astrophysicist considered, in the course of his series of photometric studies, the practicability of a standard of incandescent platinum, the intrinsic brightness of which was to be defined in terms of the heating current but he was unable to establish any simple relation between the luminous intensity and the current.

Schwendler[18] in 1878 revived this idea in modified form, but without success. The inherent difficulty, as has been pointed out by Liebenthal[19] lies in the rapid disintegration of the platinum whereby the temperature for a given strength of current is subject to considerable change.

In the following year (1879) appeared in its first form the platinum-unit of Violle[20] which five years later was adopted by

[16] E. L. Nichols: *Am. Jour. of Science*, Vol. XVIII, p. 446. (1879)
[17] Zeollner: *Poggendorff's Annalen*, Vol. C, p. 381, and CIX, p. 250.
[18] Schwendler: *Zeitschrift für Angewandte Elektricitätslehre*, Vol. II, p. [illegible]
[19] Liebenthal: Praktische Photometrie, p. 132.
[20] Violle: *Comptes Rendus*, Vol. 88, p. 171.

the International conference at Paris as the fundamental unit of luminous intensity. This unit has much to recommend it. In the first place temperature cannot be more directly and accurately defined than by the melting-point of a pure metal. The composition of the light from melting platinum corresponds more nearly to that of modern light sources, than that of candles, or of the carcel, pentane or hefner standards. The increase of intensity to about 20 candles is a distinct advantage.

The history of the abandonment of the violle, largely as the

Fig. 4.—Petavel's test of the Violle platinum standard.

result of Lummer's[21] adverse report, on the score of impracticability and the discussion of the various modifications and substitutes proposed, does not belong to the period here being considered. It should be noted, however, that Petavel's[22] experiments, in which hydrogen was used instead of coal gas in the blast lamp for melting the platinum, indicate that Violle's standard is neither impracticable nor inaccurate. The curve which gives the intensity before, during and after solidification (See Fig. 4) shows a period of nearly a minute during which the constancy is all that could be desired while successive trials agreed within less than one per cent.

[21] Lummer: *Zeitschrift fur Instrumentenkunde*, Vol. XI, p. 161.
[22] Petavel: *Proceedings of the Royal Society*, Vol. LXV, p. 469.

CONCLUSION.

That demand for accurate and reproducible standards of light arose with the development of the two great industries of gas-lighting and electric lighting. Gas photometricians and electrical engineers worked at the problem quite independently and have been long in reaching a common ground. Real progress began only with the definite abandoning of the candle and the search for new sources of light.

Most of the work belongs to a later period than that covered by these notes although several of the most interesting and important investigations had their origin before the year 1884. Thus the Harcourt[23] pentane lamp made its first appearance in 1877 and the gas standards of Methven[24] and of Giroud[52] date from 1878 and 1882 respectively.

Exceedingly interesting proposals made independently by Violle, Swinburne, Thompson and Blondel to use the light from the positive crater of the carbon arc as a photometric standard were based upon Abney's[26] observation in 1878 of the constancy of the intrinsic brightness of this source.

This proposition which like that of Violle for a platinum standard was abandoned as infeasible would seem to have a sound foundation since the constancy of the temperature of the surface of the crater has since been established by the investigations of Waidner and Burgess[27] at the U. S. Bureau of Standards. Complete reproducibility would be a question therefore of control of the location of the crater and of the use of a standard quality of carbon.

The really serious attempts at standardization in these various cases occurred however after the close of the period with which the present paper has to do and form a part of the modern rather than of the early history of photometric standards.

23 Harcourt: See Loebenthal: Photometri, p. 122, et seq.
24 Methven: *Journal of Gas Lighting*, Vol. XXXII, p. 94.
25 Giroud: *Journal des Mines and Gas*, May, 1882.
26 Abney: *Proceedings of the Royal Society*, Vol. XXVII, p. 157.
27 Waidner and Burgess: Bulletin of the Bureau of Standards, Vol. I, p. 109.

EFFECT OF THE VARIATION OF THE INCIDENT ANGLE ON THE COEFFICIENT OF DIFFUSED REFLECTION.[1]

BY F. H. GILPIN.

Although many values that closely approach each other have been obtained as the coefficient of reflection for various types and colors of surfaces, no definite information has been given as to the effect of the variation of the angle with the normal of the incident ray.

Were it possible to obtain for this purpose a number of surfaces

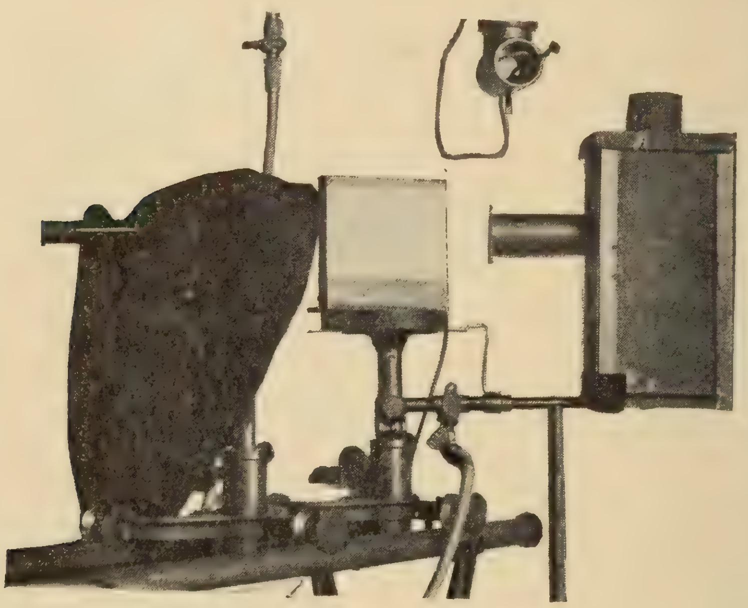


Fig. 1.—General view of apparatus.

of various colors that were perfect diffusers the problem would be comparatively simple, as the variation of the intensity would follow the cosine law, the maximum equaling unity at the normal reflected ray. This fact will be discussed later.

However, as the surface in hand varies more and more from the quality of a perfect diffuser, the shape of the curve varies more from a circle or the perfect cosine curve until, for a perfect

[1] A paper presented before the Philadelphia Section of the Illuminating Engineering Society, October 21, 1910.

reflector, there is only one point which is at an angle from the normal equal to the angle formed by the incident ray.

In order to furnish a criterion by which to judge of the effect of the different incident angles on the variation of the coefficient of reflection when various types of surfaces are used, a photometric curve of the reflected light in the plane of the incident ray must be determined. From the curve thus obtained the ratio of the lumens reflected to the lumens incident on the plane may be calculated for each incident angle.

In the apparatus used to obtain the curves, a spot of light, with sharply defined edges, was thrown on the sample surface which rotated about a central vertical line in its plane, the surface coinciding with the plane shown in Fig. 2.

The light source was an upright mantle gas burner with a

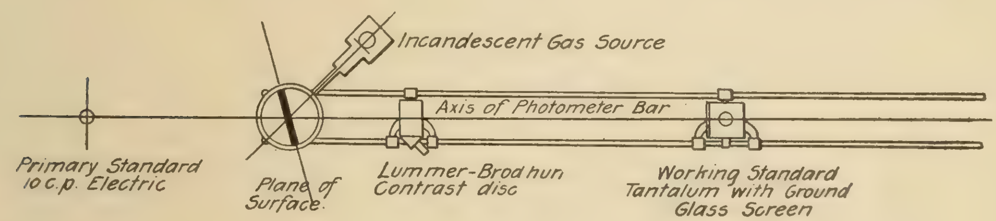


Fig. 2.—Section of apparatus.

clear chimney. A seasoned mantle was used to insure a constant value of the source during a set of readings. The light source revolved and the test plane rotated, either together or separately, through 360° about the same axis. Suitable pointers and a graduated scale indicated the relative position of the plane and the source and the angle between the plane and the axis of the photometer. A tantalum lamp, behind a ground glass screen, was used as a secondary bar standard of about 2.5 candles; it was checked at frequent intervals against a standard 10-c-p. carbon lamp. The disc box used was a Lummer-Brodhun contrast prism. All parts of the apparatus were suitably shielded from each other and from all stray light.

Owing to the interference of the light source and the disc box, readings at certain angles could not be obtained. The corresponding points on the curves were obtained by interpolation or extrapolation, which was comparatively simple, owing to the regularity of the curves.

In calculating the percentage of light reflected from a surface. two quantities must be determined; first, the total amount of light falling on it, or incident light, and, second, the total amount of light given off by the same surface, or reflected light.

To obtain the former, four quantities must be determined: (*a*)—The distance of the effective center of the light source from the axis of the surface in feet. (*b*)—The area of the light spot on the surface in square feet. (*c*)—The intensity of the light source in candles. (*d*)—The angle between the incident ray and the normal.

The first quantity was determined once for all by revolving the light source into the line of the axis of the bar, where a direct comparison is made between it and the standard lamp. A large number of readings with the disc box at various positions was then taken. Then by equating the candle-powers observed at the various points the distance of the effective center from any fixed point was obtained. This distance was found to be 27.63 cm. or 0.905 ft. from the axis of the surface plane.

The area (*b*) was obtained by direct measurement, as it represents a series of oblique sections and does not follow the cosine law, as would a series of similar sections of a cylinder. The maximum difference was about 4 per cent., due to the divergence of the ray of light.

The intensity of the light source (*c*) was determined by direct reading in place on the photometer bar.

Angle (*d*) was read directly from disc and pointers.

The computation is as follows:—

$$\text{Incident lumens} = \frac{\text{Area} \times \text{c-p.} \times \cos\theta}{d^2}$$

where c-p. = intensity of source.

θ = incident angle.

d = distance from effective center of light to center of spot on plane.

The angle for any incident ray having been selected, the light source and plane were clamped for that angle; both were then revolved about the fixed axis and five readings on the photometer were made at each of the 15° reflected light stations. From these data the candle-power was calculated according to

the inverse-square law, and a curve was plotted on polar co-ordinates for each such incident angle.

From this curve values were taken at ten prescribed equal zone angles in each quadrant, such that their average gave the mean hemispherical candle-power. The mean hemispherical candle-power multiplied by 2π gives the total lumens or the total reflected light.

In the following demonstration the coefficient of reflection is obtained for paper designated as No. 5 at an incident angle of 45°.

Incident Light:—The area of the lighted surface having been

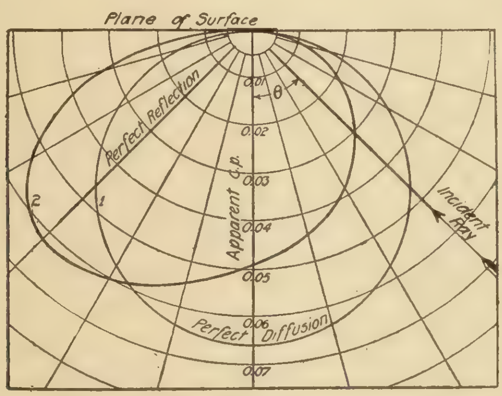


Fig. 3.—Theoretical and actual reflection.

found by measurement and calculated to be 0.0426 sq. ft., at 45° the equation for incident light is reduced to:

$$\text{Incident lumens} = \frac{0.0426 \times \text{c-p.} \times 0.707}{(0.905)^2} = 0.0368.$$

Candle-power of source = 11.93.

Incident light = 11.03 × 0.0368 = 0.439 lumens.

Reflected Light:—In Fig. 3 are shown two curves marked (1) and (2), taken in a horizontal plane. No. 1 is a theoretical curve for a perfect diffusing surface for light at any incident angle, but drawn to have the same mean hemispherical candle-power as No. 2. This curve, it will be noted, is a circle and its maximum candle-power will always show at 0° and its average candle-power will always be one-half the maximum. No. 2 is the curve as actually obtained on paper No. 5 with a 45° incident angle. It is decidedly not a circle and has none of the characteristics of No. 1. Therefore, values must be read off at

the equal zone angles shown by the dotted lines and their mean thereby determined.

In order to show the difference between these characteristics, the value at 0° and equal zone angles are here tabulated.

Angles for equal zones	Reflected candle-power No. 5 paper		Reflected candle-power Theoretical curve	
	Left side	Right side	Left side	Right side
87°–8′	0.007	0.002	0.0330	0.0330
81°–22	0.020	0.006	0.0990	0.0990
75°–31	0.031	0.011	0.1650	0.1650
69°–31	0.041	0.015	0.2313	0.2313
63°–15	0.049	0.019	0.2975	0.2975
56°–38	0.056	0.023	0 3637	0.3637
49°–28	0.060	0.028	0.4297	0.4297
41°–25	0.062	0.033	0.4958	0.4958
31°–47	0.061	0.037	0.5620	0.5620
18°–12	0.056	0.043	0.6280	0.6280
	0.444	0.217	3.3050	3.3050
	0.217		3.305	
	20) 0.661		20) 6.61	
	0.03305 = M. H. S. C. P.		0.03305	
0°	0.0492		0.0661	

which gives 0.03305 × 6.28 = 0.2075 lumens reflected.

$$\text{Efficiency} = \frac{0.2075}{0.439} \times 100 = 47.4 \text{ per cent.}$$

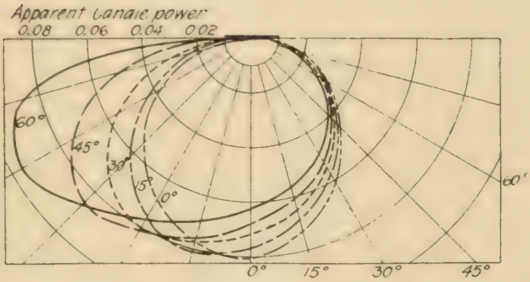
In the accompanying table and curves are given the results obtained from twenty samples of standard wall covering and a white blotter.

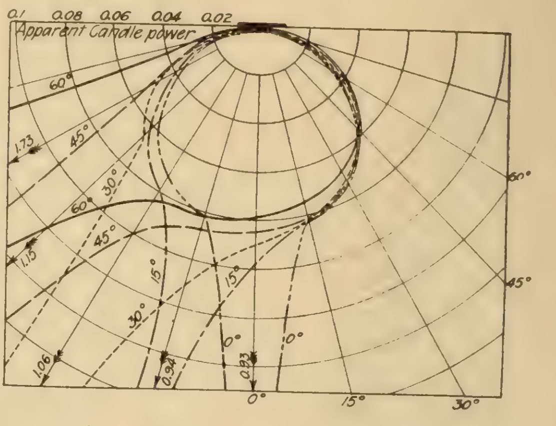
Apparently for a matt surface the greatest efficiency is obtained at 45° angle of incidence, while for other types of surfaces the angle of maximum efficiency varies—as a rule increasing with the angle. For two like colors but different surfaces there is quite a different efficiency, as in 10, 7 and 18; 13 and 14; 15 and 16; and 11 and 12.

Taking the above as a basis, the general effect on illumination with various wall coverings, assuming the same colors, could be stated as follows:

For high narrow rooms, for indirect lighting, or where the lamps are placed near the walls, a glossy paper will give the best results, while for wide flat rooms or centrally located lamps, the difference between the rough and the smooth papers would be practically negligible.

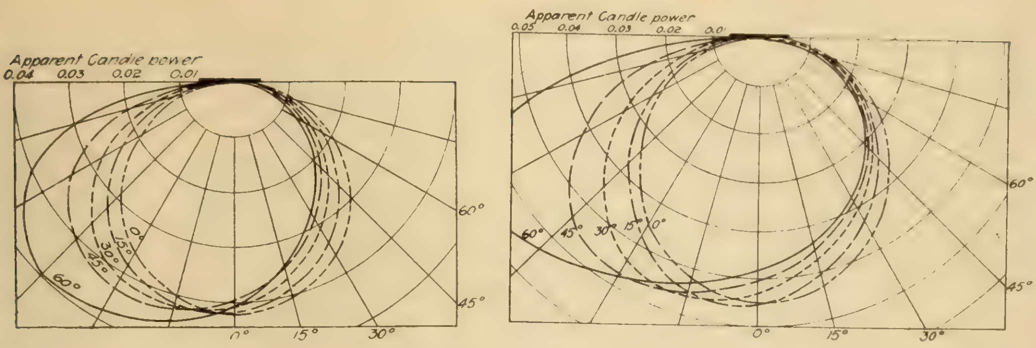
Kind of paper	Finish	Color	Efficiency of incident angle with normal of— 60°	45°	30°	15°	0°	Mean	Paper No.
Pulp tint	Matt (smooth)	White	56.0	61.5	58.2	56.5	54.6	57.3	1
Pulp tint	Matt (smooth)	Light buff	46.0	47.4	45.7	43.8	42.7	45.1	5
Pulp tint	Matt (smooth)	Lt. orange yel.	42.5	44.1	43.0	42.5	42.4	42.9	6
Silk fiber	Semi-gloss	Orange yellow	38.5	36.0	33.3	31.4	30.0	33.8	7
Silk fiber	Semi-gloss	French gray	37.6	32.2	25.6	22.6	21.0	26.0	4
Silk fiber	Semi-gloss	Lt. pea green	27.8	25.7	21.4	18.9	18.5	22.2	13
Silk fiber	Semi-gloss	Dk. pea green	23.5	18.6	14.4	11.2	9.3	15.4	15
Silk fiber	Semi-gloss	Light brown	16.8	14.6	11.7	10.9	10.3	12.9	9
Silk fiber	Semi-gloss	Light blue	15.5	13.0	10.0	9.2	8.1	11.2	19
Silk fiber	Semi-gloss	Cherry red	13.7	11.8	8.9	7.0	6.3	9.5	10
Imported stock	Fibrous	Tan	19.3	19.0	17.3	16.3	15.7	17.5	8
Imported stock	Fibrous	Light blue	13.5	13.4	12.0	11.0	10.2	12.0	17
Duplex	Rough	Light blue	12.7	12.0	10.5	9.1	8.2	10.5	18
Duplex	Rough	Cherry	6.6	6.4	6.2	6.0	5.7	6.2	11
Plain	Rough	Yellow buff	31.4	34.3	35.6	35.6	35.0	34.4	3
Plain	Rough	Lt. pea green	21.5	20.4	19.8	18.8	18.2	19.7	14
Plain	Rough	Dk. pea green	13.4	12.7	11.3	10.7	8.9	11.6	16
Plain	Rough	Deep red	7.3	7.0	5.9	5.3	4.9	6.1	12
Varnished tile	Glossy	Cream	66.3	71.1	73.1	71.8	70.8	70.6	2
Imported	Embossed gloss	Gilt	54.0	49.3	43.7	37.7	27.0	41.7	20
White blotter	....	....	72.7	80.0	73.9	72.9	71.1	74.0	..



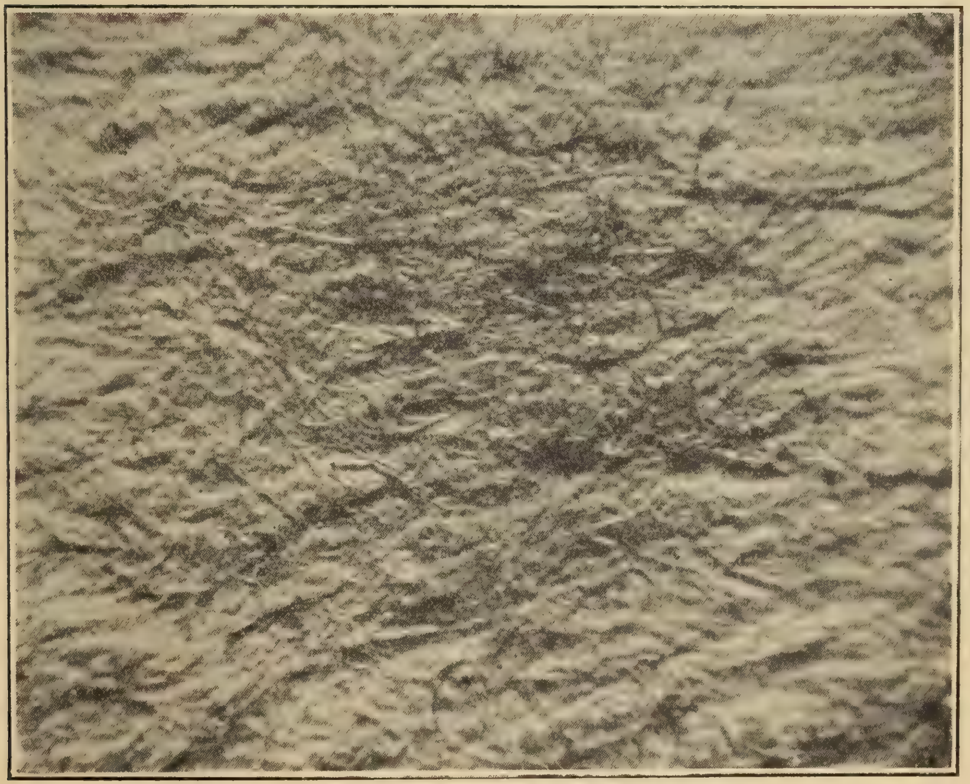


Tests of papers 1 and 2.

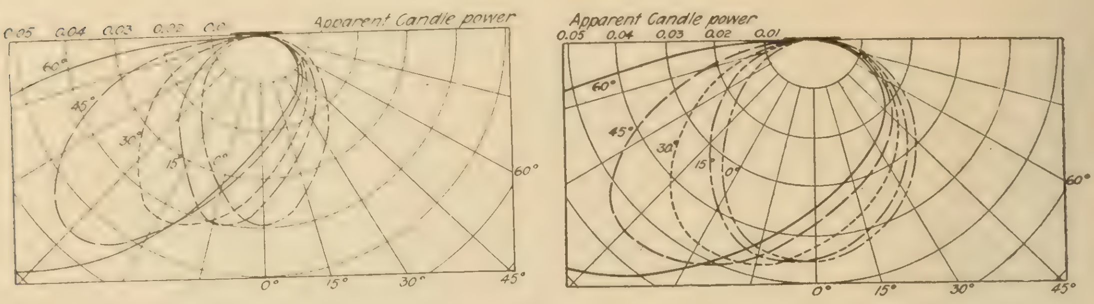
Micro-photograph of paper No. 2.



Tests of papers 3 and 6.

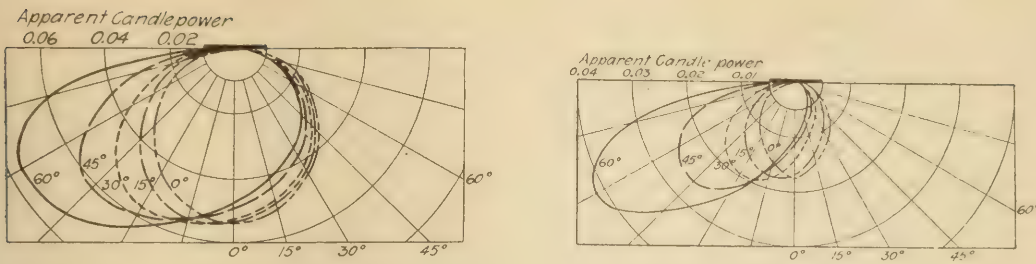


Micro-photograph of paper No. 3.



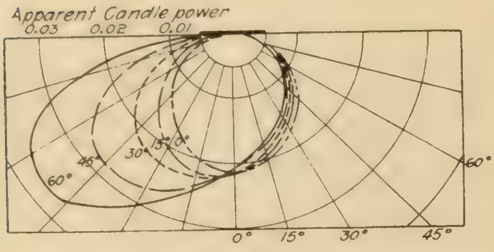
Tests of papers 4 and 7.

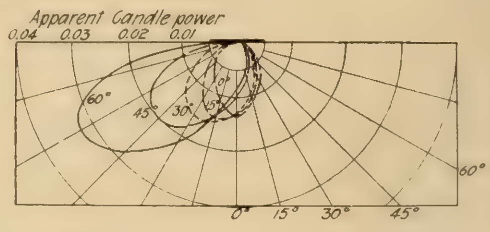
Micro-photograph of paper No. 4.



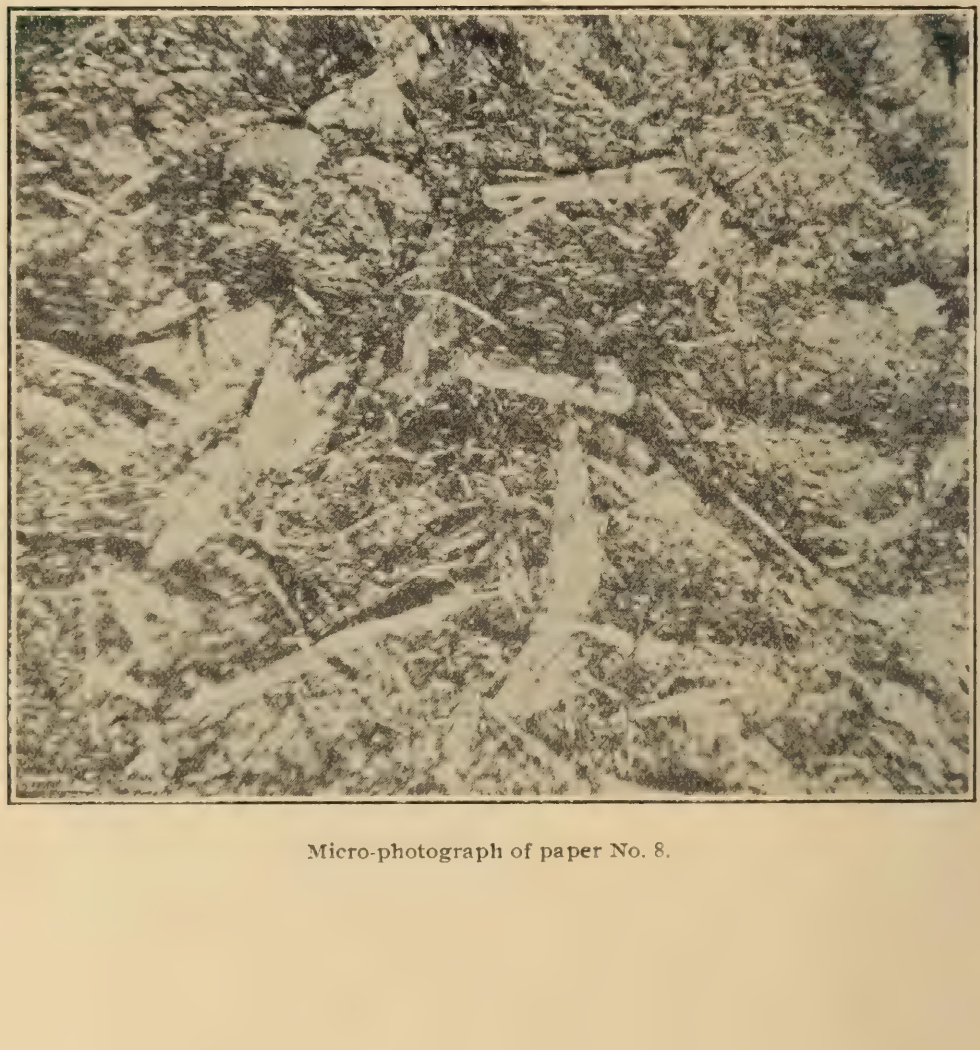
Tests of papers 5 and 9.

Micro-photograph of paper No. 5.

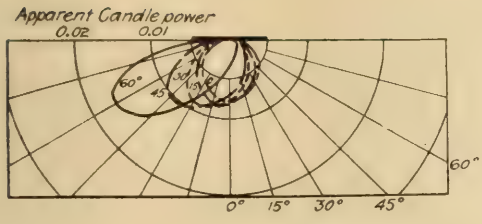


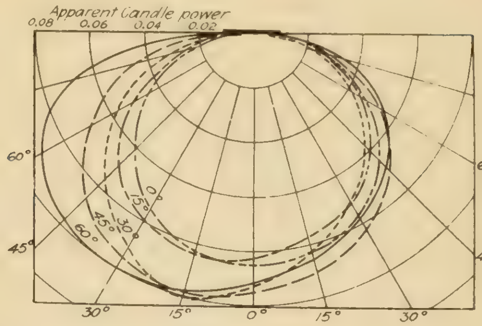


Tests of papers 8 and 10.



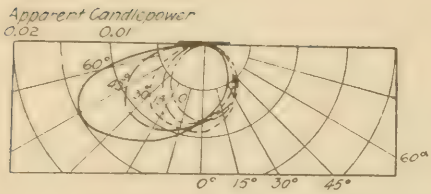
Micro-photograph of paper No. 8.

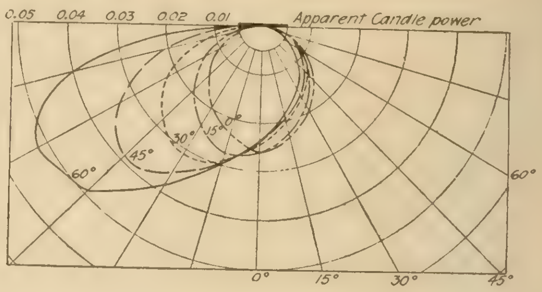




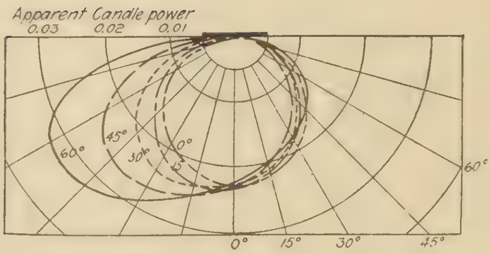
Tests of paper No. 11 and white blotting paper.

Micro-photograph of white blotting paper

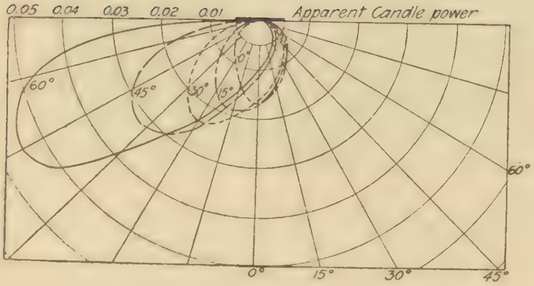


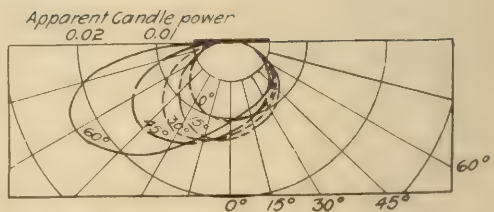


Tests of papers 12 and 13.

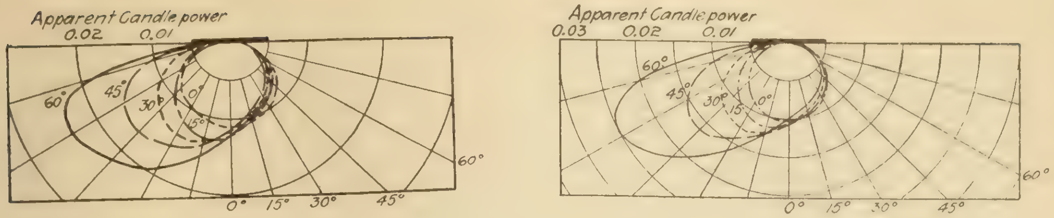


Test of paper No. 14.

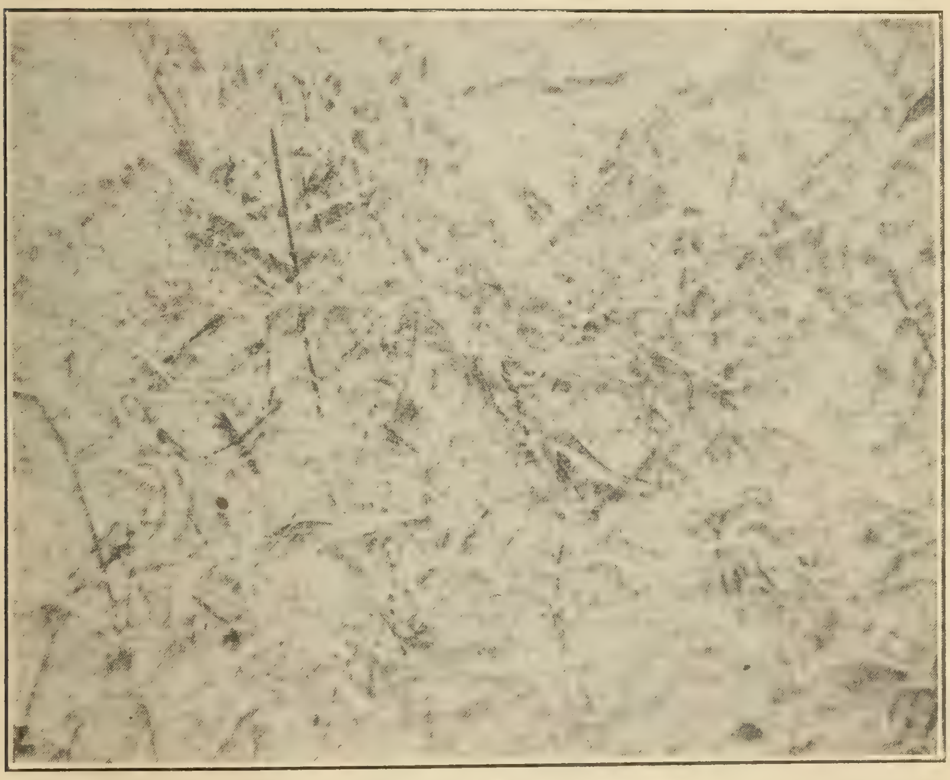




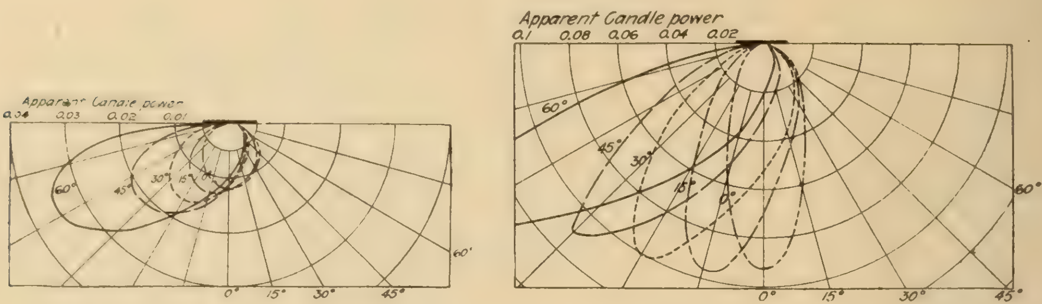
Tests of papers 15 and 16.



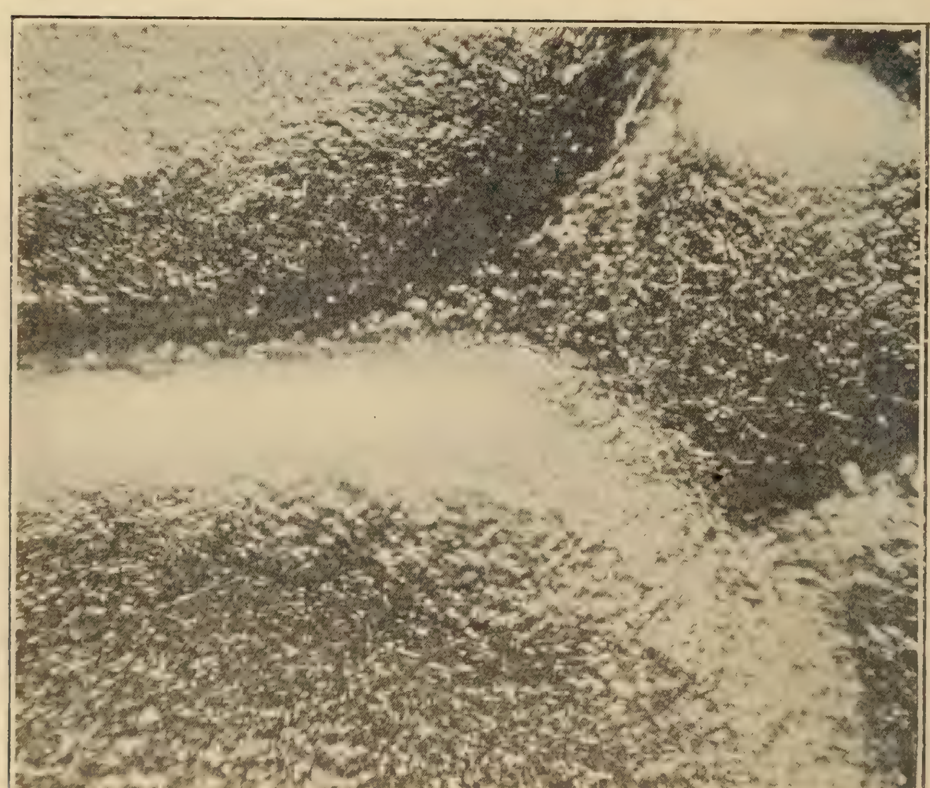
Tests of papers 17 and 18.



Micro-photograph of paper No. 18.



Tests of papers 19 and 20.



Micro-photograph of paper No. 20.

DISCUSSION.

Mr. J. D. Israel:—The author is to be congratulated upon the manner in which he has presented his paper, for he shows just how to arrive at the practical results which should give good illuminating effects. The majority of us, being connected with illuminating companies, for good reasons wish to interest those people who are associated with us outside of our companies. We should be informed on these scientific principles and understand why we recommend certain things to these outside allied interests. It is necessary for us to learn the scientific principles.

We should acquaint such people with the principles that are mentioned in the paper, let them know what the paper means to them, and tell them what they should produce to get not only aesthetic effects, but also to get good illuminating engineering effects. We should recommend our society to decorators and architects. We should recommend to consumers what kind of paper they should use to give them the best results in their various rooms. While all of us do not apply these scientific rules, I think all of us ought to realize how much they are worth to the commercial men.

Mr. Geo. S. Barrows:—How does the author determine the distinction that he makes between high, narrow rooms, and wide, flat rooms, and the kind of paper which should be used in each?

Mr. Gilpin:—The highest efficiency for glossy papers occurs at the highest angle of reflection, as a higher reflected value is obtained from them where the light is near, while for a light lower down the angle of reflection will be greater, and the best results will be obtained from the paper that has the highest reflecting value at a smaller incident angle. Most of the papers are much alike, the smoother papers giving good results at the lower angles of reflection. A glossy paper and a white smooth paper do not have the same reflection values. Papers Nos. 13 and 14 are both light pea green, having a close color match. At 60° incident angle about 28 per cent. reflection is obtained with the glossy, and about 21.5 per cent. with the smooth paper, the former giving the greater efficiency on the horizontal plane; whereas, at another angle, say 30°, there would be only about one per cent. difference. No. 13 shows 25.7 per cent. at 45°, 21.4

per cent. at 30°, and 18.9 per cent. at 15°, and No. 14 shows 19.8 per cent at 30°, and 18.8 per cent. at 15°. With a low ceiling the reflection would be about 18.9° per cent. and 18.8 per cent. which would give about the same results with either the rough or the shiny papers.

Mr. W. H. Fulweiler:—The results reported in this paper are somewhat complicated by the variation of both the texture and color of the samples examined. Would it not be possible to secure samples of the blank stock of the different varieties of the papers that were examined and after bleaching determine their values at the different incident angles? In this way the color effect would be eliminated to a considerable extent.

Mr. Gilpin:—The smoother papers as a rule were made in lighter colors, and the rougher papers in the darker shades. This may be noticed in the angles of papers examined.

Mr. Geo. S. Barrows:—Apparently some of those papers are made out of dyed pulp. Would it make any difference if the color was printed on the paper? Do these same principles apply to painted surfaces?

Mr. Gilpin:—I imagine that in some of the bluish papers the color was dyed in, whereas in the others the color was put on afterwards. In the duplex papers the colors are different on back and front. As regards the paint, I do not think there is enough difference in this to be noticeable except in the case of a sand-faced wall. The same effect would be obtained with the smooth paper as with the rough, unless the surface was varnished.

Chairman, Wm. J. Serrill:—If the paper is a perfect reflector, and the beam of light is incident on the paper at an angle of 45°, all the light would be reflected at 45°. At the other extreme, if the paper is a perfect diffuser, no matter what is the angle of incidence of the beam of light, there would be obtained a circular curve, so that whether the light comes on at 60°, 45° or at 15°, the intensity of the reflected light is still maximum at 90°. Can the areas of the curves be taken to represent comparatively the volumes of light reflected from the papers?

Mr. Walton Forstall:—As I understand it, were it not for the diffusion caused by the paper, the curve would be a straight line.

Mr. Gilpin:—Yes, and the more the reflection the greater will be the distortion.

Mr. Walton Forstall:—Paper No. 3 shows a lower percentage of efficiency than does paper No. 2. Why is that?

Mr. Gilpin:—It is due to the difference in color.

Mr. Walton Forstall:—I had an idea that since the curve of paper No. 3 is more nearly circular that that of any other paper shown, No. 3 would show the highest efficiency in the table. I understand now that the difference in color plays a strong part in the values, and hence the relative efficiencies in the table cannot be predicated by the approach of the various curves to a circle.

Chairman:—The color may affect the size of the curve, but the shape of the curve is almost entirely a function of the surface of the paper.

Mr. Gilpin:—That is what I tried to find out. There does not seem to be any degree of roughness or smoothness that gives any definite result. There may be a maximum or minimum point of diffusion due to roughness or smoothness; I do not know what it is.

Mr. Preston S. Millar:—I fancy that none of us quite appreciate the difficulty, the amount of labor and time spent in Mr. Gilpin's investigation. The care that has been exerted on each little detail is reflected in the paper; it is easy to see that each step has been very carefully considered. An investigation was made to determine the effective centre of the incandescent mantle light source. I wish the author had stated where that effective centre lay; it would be valuable to photometrists to have in mind, and in that same connection it seems to me that unless that is stated, he will have gone to a great deal of trouble for nothing, because there is a form of incandescent electric lamp in which the filament is actually in one plane, and the centre of the light source can be established in about two minutes, instead of establishing it by the elaborate process here employed for the incandescent mantle.

Has the author taken into consideration the possibility of any variable being introduced by alteration of the direction of incident light? It is possible that if the light were brought under the paper from a direction removed from that in which it was

incident in the first place, the reflection might be slightly different.

I am sorry Mr. Gilpin inserted that paragraph where he says:—

"For high narrow rooms, for indirect lighting, or where the lamps are placed near the walls, a glossy paper will give the best results, while for wide flat rooms or centrally located rooms, the difference between the rough and the smooth papers would be practically negligible."

Before one can say what will be the best decoration for a room, he must find out what is best, and it is questionable if we can state without qualification what is the best. I do not think a photometer room with a photometer bar is the best place to investigate the effect of papers on high narrow rooms and wide flat rooms, and I regret that such conclusions should be drawn from an investigation of wall papers, although the investigation in itself is a very admirable piece of work.

Mr. Gilpin:—I used a ¾ in. circular hole in the diaphragm to determine the effective centre.

Mr. Millar:—Did you use ground glass?

Mr. Gilpin:—No, it was a thin plate, no glass at all.

Mr. Millar:—Then the effective centre was nearer the disc surface than the surface of the mantle?

Mr. Gilpin:—Yes, in this case. I investigated the difference of reflection at 90° and at 45°, and found it would not make much difference with a paper that had a granular or a smooth surface. There were no definite results obtained in regard to the actual effect in rooms; the time was too short.

Mr. W. F. Little:—I wish to express my appreciation of the paper, with particular reference to the complete description the author gives of his methods. We read frequently of the absorption and diffusive powers we should expect from different surfaces, but are usually left in total ignorance of the limitations of the values given. Does the author believe it safe to assume that the total flux from a surface is proportional to the single plane investigated, when the plane investigated is that of the incident light? Suppose the plane studied had been taken both perpendicular to the surface and to the plane of the incident light, would the curve so obtained be a circle as assumed? Some street investigation work done in New York, though hardly in

this line, still substantiates some results given in the paper. The reflected light in various angles around a spot on the street was measured, and it was found in some cases that, as the author has shown, the peak in the plane of incident light would give the same average value as the plane investigated by him. Are the values given in the paper proportional to the total flux from the surface studied?

Chairman Serrill:—Mr. Little probably refers to the mathematical assumption as to the light emitted. Mr. Gilpin put a spot of light on the paper, and plotted a polar curve around this spot considered as the source of light. Having obtained this curve, he multiplies the average candle-power obtained from it by 2π and thus gets the total lumens. It is not entirely clear that the assumption here made is correct.

Mr. Gilpin:—I used Dr. Rosa's theory about light distribution from a small disc. Instead of the disc, a spot of light was used. In the case of a perfect circle of light distribution from a spot of light, the same plane section is gotten on any diameter. With a distorted curve the surface of revolution would be somewhat changed.

Mr. Preston S. Millar:—If I may say another word, I think the relations can be made clear by stating them in this way: Suppose that with a mirror; the light is incident at 40°, and on the same plane the reflected light would have a very high value. For investigating that plane we measure that reflected value, and assume that in all other planes there is the same value, but there would be practically no light in any other plane, and one would have to average the light in every plane, which would show decreased values, whereas in the first place the value would be high. Possibly there is some allowance to be made for such results. Certainly I do not think any such exhaustive research has been made before on this subject, and we now know a whole lot more about wall papers than we did formerly.

GOOD LIGHTING FROM A FACTORY VIEWPOINT.[1]

BY JOSEPH NEWMAN, JR.

The keynote of the modern factory system is efficiency, and efficiency is greatly aided by keeping production at its maximum during the entire length of the working day. Those who are familiar with factory conditions know how great is the tendency of production to slacken as the hours of darkness approach, thus lessening the total output and decreasing the shop efficiency. In some measure this slackening may be due to the fact that the average human being cannot maintain the maximum pace for the standard factory day of ten hours. However, this does not enter into the present discussion.

The other most potent reason for this falling off is in the majority of shops the difficulty of approximating daylight conditions by means of artificial light. Few factory managers in the past have been willing to believe that money spent to make the transition from daylight to artificial light as little apparent to the employees as possible would pay dividends. It may be that before the advent of the new high-efficiency lamps he was right, as the expense of tripling or quadrupling the lighting he then had, as many would have had to do, would have nearly counterbalanced the gain in production, especially as the cost of additional equipment would be a large item. This is most true of those factories which have a good supply of natural light during working hours for a considerable portion of the year.

The development of more efficient methods of lighting has been coincident with the increasing pressure of higher labor and material costs in all lines of manufacture. Economies which would not have been considered a few years ago are eagerly sought after and put into effect. Waste is abhorred as greatly as scientists used to believe that nature abhorred a vacuum. Lack of light has undoubtedly caused a large amount of waste human energy and of material. As labor has become more valuable and more independent, the comfort and well being of

[1] A paper presented before the Chicago Section of the Illuminating Engineering Society, on October 13, 1910.

employees have been seen by the more broad minded to create a valuable asset in the lessening of these class differences which cause so much economic waste. Well lighted, well ventilated shops make for peace of mind and are very important factors of an efficient organization.

Another reason for insisting on the economy of good lighting is the bearing it has on the accident account. It has been brought home to us that the price paid for the privilege of maiming our fellow men has been too high. Millions of dollars are paid every year because of unguarded machinery and badly lighted shops. If the injured were being compensated for their injuries the situation would not have aroused so much public interest, but the fact is we are using the money which should go to this end to feed a small army of lawyers. As it is perfectly feasible to eliminate accidents due to lack of light in our shops, it should be done from a humanitarian and conservation standpoint.

It has become axiomatic in the mercantile world that the best possible lighting is a very valuable asset and the idea has slowly percolated down to the shop. The factory manager is now asking for good light, and how it may be obtained at a reasonable cost. When he asks for good light he means such light as will prevent accidents and keep the rate of production in the shop as high as during the hours of daylight. If attention is concentrated on the latter consideration it will invariably be found that prevention of accidents has been cared for at the same time.

To obtain maximum returns for the smallest outlay, consideration must be given to the article manufactured and all the attending circumstances, such as the possibility of keeping shop walls and ceilings clean and of a light tint, the color of the manufactured product, the size of the parts made and the operations performed on them. The shape of the machines used for the various operations has considerable to do with the amount and distribution of the light, as have also the degree of accuracy necessary and how nearly the machines are automatic. It is also necessary to consider the number of parts per unit of time and the closeness with which it is necessary to inspect them to detect flaws. The modern factory is, as a general thing, on a piecework basis, and this has a bearing on the amount of light

required, as poor light means poor and careless work passing undetected.

It is appropriate to take the different parts of the shop in turn and consider their requirements, commencing with the foundries and following the processes in the shop to their completion, and the storage of the machines in the warehouses.

In the foundries, where the larger castings are made, the lighting must be fairly even, avoiding dense shadows, but the intensity need not be great. Buildings used for this class of work are always provided with cranes, and lamps must be hung high to avoid them. This means units of high candle-power and enough of them to overcome the great absorptive power of the black moulding sand. For small castings not only must good general illumination be secured, but each molder must be supplied with a small unit at his bench or stall for the accurate setting of cores and finishing molds. This is especially true of malleable foundries where the castings are thin and of intricate design. As a general thing the benches are so arranged that the molder works with his face to the wall and the light comes over his shoulder. The intensity required is so great and the amount of space occupied per man so large that it is impractical to raise the general lighting sufficiently to do away with the hand lamps. It is also impossible to change the position of the molding floors. In all cases of this kind the lighting must conform to the other requirements of operation, it being one of the conditions of every lighting problem in a factory that the plan of the shop is fixed and the lighting must be arranged to suit this plan.

Malleable foundries require a larger amount of general illumination than do those in which gray iron is made, as, on account of the method of pouring and the high temperature of the metal, great quantities of steam and smoke arise from the molds, which in cold and humid weather make adequate lighting almost impossible. This condition lasts only a short time during the latter part of the heat and as the molds are cooling, but unless the ventilating conditions are exceptional the fog is dense. In foundry work, where no help can be obtained from reflecting surfaces, it is necessary to expend enough energy to furnish from one-half to one candle-power per square foot of floor area,

depending upon the height at which it is necessary to hang the lamps and the amount of smoke and vapor generated. This value ignores all portable lamps which it may be necessary to provide for the finer work. With machine molding, where the machine is moved over the whole floor, the general illumination described is almost always sufficient, very few portable lamps being necessary. For heights less than 20 feet, units of 300 or 400 candle-power, with good reflectors, give the best results, the light being given a more or less extensive distribution.

In machine shops, where general cleanliness can be maintained, a smaller expenditure of energy than in foundries will give good results. The work must be well lighted but the general surroundings do not need a high degree of illumination. An expenditure of energy resulting in the lighting of four square feet per candle-power will with good reflectors be sufficient if the light is well distributed. This means from 0.5 to 1.5 foot-candles on a plane thirty inches from the floor, the lamps being hung 10.5 feet high.

The machine shops I assumed are those where most of the parts are small, ranging in size from 1 to 100 pounds, and the operations are of a more or less simple nature, such as drilling and facing and the simplest kind of lathe work. A large part of the operations are performed by placing the castings in jigs and starting the tool. Very little judgment is required, the operator's ability being limited to rapid movement. In this class of work, where the whole shop becomes, as it were, one large machine the material following one definite course from department to department group, driving with a multiplicity of belts and shafting is the rule. This is further complicated by posts at frequent intervals obstructing the view and casting more or less dense shadows.

Lamps of comparatively small size seem best suited to these conditions, 80 candle-power being a convenient unit. Where lamps of twice this size or larger have been tried a far greater number of 8-c-p. and 16-c-p. lamps must be installed to give the desired results. This increases the first cost of the equipment and also the maintenance cost. Large enameled intensive shades are the most useful, as wide variation in light between the lamps

is not objectionable, and in order to get the best results as economically as possible it is necessary to place the lamps at irregular intervals, concentrating the light on the work and tools, except in the main gangways. Lathes are practically the only machines of this type which require individual lamps.

Where punching and forming presses are used, each machine must have one or more small lamps on some form of adjustable fixture, as the work and dies cannot be fully reached by any general scheme of illumination. Lamps of the 8-c-p. size seem to be the best suited to this class of work with the 80-c-p. lamps under extensive shades for general lighting.

Wood shops are easily lighted by the judicious placing of intensive units over the machines. Almost all of the work can be lighted from the top, the ability to see the grain of the wood being one of the most important points. From its color, wood is easy to light, and the results from the same expenditure of energy as in machine shops are highly gratifying.

In paint shops where the results wanted are broad and considerable dipping is done, the illumination needed is no greater than in machine shops. The intensive shade has the largest place in this class of work, also striping and work of like nature require a greater intensity and this is obtained by lowering the lamp and using a closer spacing.

In warehouses, which are only used for storage, a very low intensity is all that is required except along the main gangways where there is much traffic. Lamps of 16-c-p. spaced 16 feet apart under flat shades answer very well. These lamps should be placed as close to the ceiling as possible so that the stock may be piled almost up to the roof girders. An evenly distributed light is what is needed, the most important point in a case of this kind being that the light shall always be ready for use when wanted.

The lighting of a factory is a comparatively simple matter. The one feature to which must be subordinated all others is reliability. Simplicity is the second, and cost of maintenance the third in order. Simplicity and reliability are usually found together.

It is understood that the conditions considered above are those

of a plant already in existence, with a lighting system installed and that the discussion relates to methods of bringing it up to what is considered a modern standard. First cost is often the determining factor when the necessity for a change in the lighting system has made itself apparent. This is especially true when reliability and simplicity are combined with low first cost as against alleged low cost of maintenance and energy. In fact the making of improvements and replacing worn-out apparatus without expending more than the amount usually set aside for maintenance is the condition which has to be met as nearly as possible.

A good system may be laid out, which it is well known will increase the efficiency of the shop, but the necessary funds for completely re-equipping are not forthcoming and gradual replacement is all that can be expected. This condition is one in which the tungsten lamp has proved its great value. A few lamps are purchased with suitable shades and attached to the old system of wiring. The result soon warrants an increase. The change is gradual but goes on at an increasingly rapid rate. No expert force is necessary, as any one can change a lamp and clean a shade. The supply of lamps is practically unlimited, and it is never necessary to wait for deliveries.

The author recalls a case where it was necessary on account of the uncertain hours during which a foundry needed light, combined with the age and general decrepitude of an open arc installation, to keep a man on night duty the year around. An outage meant darkness over a large part of the foundry and an open circuit meant curses both loud and deep. At its best the lighting was uneven and unsatisfactory. A large number of incandescent lamps were used as an auxiliary to the arc system. Plans were submitted but were objected to on account of the large lump sum it would have cost to completely re-equip the shop. Shortly after this the tungsten lamp came into the market and while the stories told of breakage made the venture dubious, a dozen were purchased and installed where the need was greatest. The life of these lamps exceeded expectations, and a few more were ordered. By reason of a well equipped sheet metal department, shades in the form of a large cone were easily made

from sheet iron, sign socket and aluminum paint. The foundry men found that they always had light when they wanted it without the aid of the trimmer, and that by reason of its distribution in smaller units it was far more efficient. In about eighteen months the night trimmer had been dispensed with and a system which required only about three hours attention per week for cleaning has been installed.

The success attending the foundry installation led to the use of tungsten lamps in other parts of the shops for replacing clusters. A busy season brought a demand for the maximum production of the organization, and more light was needed in all parts of the shop. The simplest and quickest method of obtaining results was the installation of 100-watt tungsten lamps, which seemed to be the ideal size for the distribution of light needed.

Better reflectors were seen to be greatly needed for maximum results. Intensive and extensive steel shades although advertised, could not be obtained. There was finally found a 16-in. porcelain enameled bowl shade which gave an intensive distribution and was very durable and efficient. With this shade and the 100-watt lamp, experiments were conducted in particularly dark rooms where the need of more light had made itself most manifest. It was found that ample light for all general operations could be obtained by 18 feet spacings at a height of 10.5 feet. One of the rooms experimented with was devoted to punch press operations, and it was found impossible to dispense with individual lamps at the machines. For this work the ideas of another institution having similar work were borrowed, and 8-c-p. lamps on the simplest form of adjustable fixtures were used.

The reflector is the factor upon which the success or failure of the lighting depends. Porcelain enamel finish is the only one which has proved itself sufficiently durable and the intensive distribution of light is the one which finds the largest use.

Reflectors are the most efficient in the larger sizes; that is, of two reflectors designed for the same distribution of light with a given lamp, the one having the largest area will give the best results.

To sum up in the light of past experience, the factory needs a lighting system at a minimum first cost even at the sacrifice of

some efficiency. It needs a system which will give 24-hour service with a minimum of unintelligent attention. It needs a unit which will fit naturally into the divisions of shop space made by the post-supported mill construction. It needs a large per cent. of the light concentrated on the machines and work but enough light in all parts of the shop area to make movement as safe and free as under daylight conditions.

The problem is not difficult to solve if attended with the same energy that is given to lighting the goods on sale after manufacture, and the author believes the time has come when it will receive that attention.

DISCUSSION.

Mr. C. W. Price:—A few days ago I visited one of the smaller works of the International Harvester Company with a Committee from Milwaukee who were investigating protection against injury. This works originally was one of the typical old style factories, with low, dark rooms, and with no adequate lighting facilities. It has recently been remodeled by one of the most progressive and enthusiastic young superintendents, with most surprising results. The members of the committee were surprised and pleased with the atmosphere of light and cheerfulness in all the rooms. Each room is white-washed and clean, and the windows are kept clean. In this factory a new system of lighting, as described by Mr. Newman, is being installed, and in some rooms the lamps are kept in service during the day so that every room in the shop is either artificially or naturally lighted during working hours. No one but men who have had experience in shops can appreciate what this means from a manufacturing standpoint. I learned the other day that in this works there is only about one-half the number of changes in the employees as in some of the other factories of the company which as yet are not so well cared for along sanitary lines. I believe the lighting is partially responsible for this result.

The superintendent of an automobile factory in Ohio said recently that he was able easily to hire men away from the other automobile factories where the sanitary conditions and the lighting are not so good. The class of men he employs are young and of a high grade. Some of them, on being questioned, stated

that the reason why they wished to work at this plant was because of the better conditions. I think manufacturers all over the country are awakening to an appreciation of better sanitary conditions in shops, not only from a humane standpoint, but much more from an economic manufacturing standpoint.

Mr. W. E. Walter:—In Philadelphia, the Curtis Publishing Company is studying out the lighting problem of its new building with a great deal of care, and my mission in Chicago is partly to see what the West has to show. Women in particular are affected by imperfect lighting. Their system seems to be susceptible to drafts, poor light, etc., and as we have in our employ several thousand women, we have taken pains to study this problem. I hope that with the assistance of illuminating engineers we may be able to solve some of these problems ourselves.

Mr. F. R. Frost:—The importance of proper lighting, as brought out by Mr. Newman, is certainly very interesting. In the first place, there is the increase in the efficiency of the men due to proper lighting, and in the second place the danger from accidents is reduced, and the increase in the output of the shop which can be brought about by the proper lighting. I think there should be more study given to factory conditions with the idea of providing more general illumination. The effect of poor lighting upon the mind and also upon the health of the men is indeed considerable, and the money spent in producing good illumination is certainly productive of dividends.

Mr. A. T. Hunt:—As far as factory illumination, as applied to railway shops, is concerned I believe that greater efficiency can be obtained from the men, as well as greater output, by using proper general illumination. As Mr. Newman said, it is absolutely necessary to have illumination at the various machines, but the fact remains that the effect upon the men, in regard to their general cheerfulness in the shop, depends largely upon the complete illumination of the entire floor; this fact is being recognized more and more.

Mr. Albert Scheible:—Did the author's studies include any data as to the actual cost of the accidents due to lighting? It was implied that there was something of that kind.

Mr. Newman:—No actual records of the cost were made. It is a matter that is pretty hard to get at in dollars and cents.

Mr. C. W. Price:—I wish to mention one point in regard to the value of light for protection against injury which has been a great inspiration and encouragement to me. One of the largest corporations in the United States, which has done the most successful work along the line of protection against injury, emphasizes very strongly the value of light. All of its rooms are well lighted, and all stairways, runways, platforms and yards are well lighted. In 1900 43 men out of every 100 employed by the company were injured and lost time, with a total of some 10,000 employees. In 1909 the number was reduced to 19 men out of each 100 who were injured and lost time. The superintendent of safety would say that good lighting had an important part in this result.

Mr. Frank Price:—Recently I went into a place where some two years ago I had occasion to make some rather radical changes in the method of lighting, and I looked over the installation, remarking to the manager that I did not see how we could change it to improve it very much. He said "You must remember one thing, Mr. Price, we keep the place clean," I then observed that every reflector was shining and every lamp was clean, and the result was an efficiency of possibly twice that obtained in the ordinary method of maintaining lighting equipment. I hope that the work along the line of improvement will bring out the keeping of a clean equipment, the lamps as well as the reflectors. That plan means an average of not less than 33 per cent. better efficiency of the lighting installation. I do not know of any one thing that would mean greater improvement than the systematic cleaning of the equipment in old installations, the proper installation of lamps in the new installations, and the installation of the style particularly suited for the case in hand.

Mr. Newman:—At the present time the International Harvester Company employs two, and sometimes more men cleaning globes and reflectors. The aim is to keep everything clean. This work is done every week, and the equipment is kept in very fair shape.

Mr. Harry Swindell:—Has Mr. Newman any record as to the actual breakage of lamps in connection with the cleaning.

Mr. Newman:—The breakage has been so small that we have never considered it necessary to keep any record of that kind.

We clean the lamps lighted, and the men realize the fact that they are fragile. I should say the percentage was very small in the size we use, that is, the 100-watt tungsten lamps.

Mr. A. D. Curtis:—The seeing power of the eye is much greater in case the lighting source is out of view. I do not have in mind indirect illumination, as few factories are adapted for such lighting. One can secure the desirable distribution of light without having the source of light in the range of vision, provided a reflector of correct scientific design for this purpose is used. I have in mind a reflector resembling a beehive in appearance. Its construction is such that a broad distribution comes from the reflector, the lamp being high enough so that unless one is almost underneath the reflector he could not see the lamp at all. Mr. J. R. Cravath designed this reflector for the Patten Gymnasium at Evanston, but it has proven particularly desirable for factory illumination. Has this reflector received any consideration in the tests of the author?

Mr. Newman:—The shade being used is 16 in. in diameter and a little over 7 in. deep. The lower part of the lamp is up in the shade about one inch, so that one must get within probably six or eight feet from it when the lamp is hung 10 ft. high in order to get in direct range. We have not found that the extensive distribution gives the best results. Of course, our whole system is based on the use of good general illumination, as well as a lamp over each machine if necessary; in the latter case the lamp is placed close to the machine.